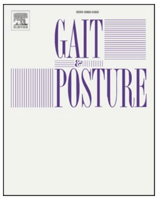
Gait & Posture 100 (2023) 284–301

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost



Does texting while walking affect spatiotemporal gait parameters in healthy adults, older people, and persons with motor or cognitive disorders? A systematic review and meta-analysis

Anne-Violette Bruyneel [a,*], Aline Reinmann [a], Simone C. Gafner [b], Jean-David Sandoz [a], Noémie C. Duclos [c,d]

[a] *Geneva School of Health Sciences, HES-SO University of Applied Sciences and Arts Western Switzerland, Switzerland*
[b] *School of Health Sciences, HES-SO Valais-Wallis, University of Applied Sciences and Arts Western Switzerland, Switzerland*
[c] *Univ. Bordeaux, INSERM, BPH, U1219, Team ACTIVE, F-33000, Bordeaux, France*
[d] *Univ.Bordeaux, Collège Sciences de la santé, Institut Universitaire des Sciences de la Réadaptation, F-33000, Bordeaux, France*

ARTICLE INFO

Keywords:
Smartphone
Texting
Walking
Ecological
Dual-task

ABSTRACT

Background: Smartphone use during postural-locomotor tasks is an everyday activity for individuals of all ages in diverse environmental situations and with various health conditions. Nevertheless, the use of smartphones during walking is responsible for many accidents.

Research question: This systematic review and meta-analysis examined spatiotemporal gait parameters during the dual-task situation “texting + gait” versus isolated gait task (single task) in adult persons (>18 years).

Methods: Electronic database searches were performed in PubMed, Embase, CINHAL, and LISSA. Two examiners assessed the eligibility and quality of appraisal with the Downs and Black checklist. The standardized mean difference (SMD) with 95 % confidence intervals was calculated to compare single- and dual-task situations. The pooled estimates of the overall effect were computed using a random or fixed effects method, and forest plots were generated.

Results and significance: A total of 25 studies were included. All studies included healthy adults, with four studies including older persons and three including people with pathological conditions. The walking task was with (N = 4) and without (N = 21) obstacles and in laboratory (N = 21) or ecological conditions (N = 7). The quality scores were 6–8/16 for eight studies, 9–12/16 for seven studies, and more than 12/16 for three studies. During the “texting + gait” tasks, the meta-analysis highlighted a significant impairment of gait speed, step and stride length, cadence, and double and single support ($p < 0.05$).

The spatiotemporal parameters of gait were systematically altered during the texting task regardless of the population and test conditions. However, the quality of the studies is moderate, and few studies have been conducted for people with motor deficiencies. The impact of texting on walking should be better considered to develop prevention actions.

1. Introduction

1.1. Background

The first text was sent 30 years ago. Since then, the cell phone has become a multitasking device and part of daily life. In 2020, 86 % of the European population subscribed to mobile services [1]. In France, 94 % of people over 12 years had a cell phone, including 84 % with smartphones [2]. Buying a public transport ticket or validating a payment are increasingly complicated tasks without a smartphone. This tool has never been more essential, regardless of life conditions or age.

Smartphone use during postural-locomotor tasks (e.g., balance,

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Abbreviations: PRISMA, Preferred Reporting Items for Sytematic Review amd Meta-Analysis; SD, Standard Deviation; SMD, Standardized Mean Difference; CI, Confidence Interval; RE, Random effect model; FE, Fixed effect model.

[*] Correspondence to: Rue des Caroubiers 25, CH- 1227 Carouge, Switzerland.

E-mail addresses: Anne-violette.bruyneel@hesge.ch (A.-V. Bruyneel), aline.reinmann@hesge.ch (A. Reinmann), simone.gafner@hesge.ch (S.C. Gafner), jean-david.sandoz@hesge.ch (J.-D. Sandoz), noemie.duclos@u-bordeaux.fr (N.C. Duclos).

https://doi.org/10.1016/j.gaitpost.2023.01.009
Received 6 September 2022; Received in revised form 7 December 2022; Accepted 15 January 2023

walking, climbing stairs) is an everyday activity for most individuals of all ages in various environmental and health situations [3]. This distraction often induces minor disturbances that are easily correctable and without consequences (e.g., loss of balance, deviation of trajectory) [4], but this dual-task condition can also cause traumas. Between 5 % and 30 % of falls and walking accidents are directly attributable to smartphone use [5]. The number of accidents attributable to this dual-task is continuously increasing [5]. Using a smartphone while walking is frequent and a high-risk activity, especially in the presence of advanced age [6] or motor limitations [7]. Young adults (< 30 years), due to the frequency of their smartphone use, and people over 60 years of age, due to their declining postural and cognitive abilities, are at greater risk of trauma than middle-aged adults [8]. Mortality due to smartphone use during walking is significantly higher for people over 65 (13–32 % of accidents) than for middle-aged adults (5–9 %) [5].

Smartphone use induces cognitive distraction, reduces visual attention to the environment, and alters motor skills through decreased arm motion and head mobility [9]. A study showed an alteration in walking behavior when crossing a street, which consisted of making dangerous decisions such as not using a street crossing [10]. Therefore, smartphone use seems to involve multiple consequences that can explain the functional disturbances and the associated risks. This daily activity is poorly integrated into rehabilitation, even though older individuals and patients often use smartphones, which are crucial social elements in their lives. In these populations with balance impairment or risk of falling, dual-task exercises improve postural control [11]. The most frequently used dual-task in the rehabilitation context is the “counting backward task” while walking but this task is not usual. Therefore, more ecological dual-task could be interesting to integrate into the exercises. As rehabilitation should be a dynamic process that adapts to changing lifestyles, the omnipresence of smartphone use in everyday life and during complex motor tasks should be considered in therapy programs. The proposition of dual-task “texting during gait” during rehabilitation could raise awareness of accidents related to smartphone use while walking, and targeted interventions could be proposed to limit risks in patients’ daily activities [3].

The postural-locomotor tasks are impaired when the individuals use their smartphone to write a text message, dial a number, browse the web, read text, watch a movie, interact with an app, play games, and take selfies [12]. In contrast, no effect was observed for listening to music on a smartphone [13]. No effect was observed during texting when walking on a treadmill [9,14,15], but the difficulty of detecting the gait speed variation during treadmill walking probably explains this. Among the tasks done on a smartphone, a scoping review [12] highlighted that texting during walking is the most studied. Crowley et al., 2016 [16] and Krasovsky et al., 2017 [3] conducted narrative reviews on this dual task. All results agree that texting disrupts pedestrian behavior and gait. However, no systematic review has been conducted on the impact of texting on the spatiotemporal parameters, and studies on pathological conditions have not been included in these reviews.

Comfortable walking speed is slowed down in the older population and people with motor disturbances [17,18]. This parameter is considered a vital sign, since a normal walking speed lower than 1 m/s induces a high risk of falls, dependence, and mortality [19]. For the dual-task “texting + gait”, the gait speed is the parameter most used to evaluate the additional impact of texting on walking [3,16]. This parameter is relevant because its reliability is good to excellent [20], and the decrease in walking speed could be associated with a substantial increase in gait variability [16] and the risk of falling [21]. However, adaptive strategies (e.g., reducing step length, cadence) can compensate for the gait instability induced by slow speed [21], and it is therefore relevant to study other spatiotemporal parameters.

1.2. Objectives

The objective of this systematic review was to compare spatiotemporal gait parameters during the dual-task situation “texting + gait” versus isolated gait task (single task) in adult persons (>18 years). We hypothesized that writing a text while walking negatively affects the spatiotemporal parameters, and that the effect is more accentuated in older people and those with pathological conditions than in healthy adults.

2. Methods

2.1. Protocol and registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis Statement (PRISMA) [22] and the JBI manual for evidence synthesis [23]. The protocol was registered at PROSPERO (registration no. CRD42021290632).

2.2. Eligibility criteria

The inclusion criteria were based on the PICO mnemonic (Population, Intervention, Comparator, and Outcome) (Table 1) [23].

2.2.1. Inclusion criteria

The *population* included male and female adults over 18 with no upper age limit. There were no restrictions regarding pathological conditions and the habit of using a cell phone.

The *intervention* was the dual-task of writing a text message on a cell phone (texting) concurrently with walking. Regarding cell phone characteristics, all studies were included without distinguishing between phone type (e.g., brands, versions), interface (e.g., keys, touch screen), or operating system (e.g., Apple, Android). Normal walking on flat ground and walking with obstacles were considered in laboratory and outdoor settings. Assessment of the walking task was isolated from other locomotor tasks (e.g., TUG was excluded).

The studies had to report a *comparison*, with the walking task in single task conditions identical to the walking task used in dual-task conditions.

The *outcomes* were the gait parameters measured during the dual and single tasks. The primary outcome was the walking speed, with secondary outcomes being other quantitative gait spatiotemporal parameters.

Regarding the design, only original cross-sectional observational studies published in a peer-review journal were included, and only published articles with a publication date less than 10 years ago were considered. This limit was justified because mobile technology has evolved significantly in recent years, and phones older than 10 years are significantly different to today’s models – for example, touch screens have since become widespread on smartphones.

2.2.2. Exclusion criteria

Studies were excluded if they focused on a dual-task other than texting (e.g., phoning, selfies, web browsing), walking on stairs, an inclined plane or a treadmill, or parameters other than spatiotemporal (e.g., street behavior). Abstracts, conference books, editorials, longitudinal studies, publications in non-peer-reviewed journals, reviews, and meta-analyses were also excluded.

Table 1
PICO details defining the criteria of eligibility.

Criteria	*Characteristics*
Population	Adults (healthy, older, or pathological conditions)
Intervention	Dual-task: Texting + walking
Comparison	Single task: Walking
Outcomes	Spatiotemporal gait parameters

2.3. Information sources

The literature search was conducted in English in peer-reviewed journals up to 09.11.2021. The following four databases were searched: PubMed/Medline, EMBASE, CINAHL, and LISSA.

2.4. Systematic literature search

The search strategy was realized by a librarian (JDS). Initially, the following keywords (MESH or not MESH terms) according to four groups based on the PICO were used in combination with the Boolean indicator “AND” and “OR”: Group 1: “adults”, “older”, “elderly”; Group 2: “phone”, “text”, “SMS”, “dual-task”, “double task”; Group 3: “gait”, “walk”; Group 4: “speed”, “velocity”. However, this approach was too restrictive, and some sources were not identified. Thus, Group 4 was removed from the search equations (Appendix 1).

2.5. Selection process

The librarian searched each database and collected articles according to the predefined search strategy, using Zotero. The results were uploaded to the Rayyan website for the screening process.

Following this first phase, the two independent examiners (AR and AVB) conducted the first screening to identify appropriate manuscripts based on the eligibility criteria. Each reviewer was blind to the other reviewer’s decisions (“Blind on” function in Rayyan).

In the first stage, manuscript titles were screened according to the eligibility criteria. In the second step, the abstracts were reviewed to identify eligible sources. In the third step, the full texts of articles that appeared to meet the inclusion criteria were read.

In case of disagreements between the reviewers (AVB and AR), a third author (ND) independently reviewed the work and discussed the decision with the other authors (AVB and AR).

A PRISMA flow chart summarizing the literature search and selection process is presented in the results chapter (Fig. 1).

2.6. Data extraction

Two examiners (AVB and AR) performed the data extraction independently using a standardized table and classifying the data according

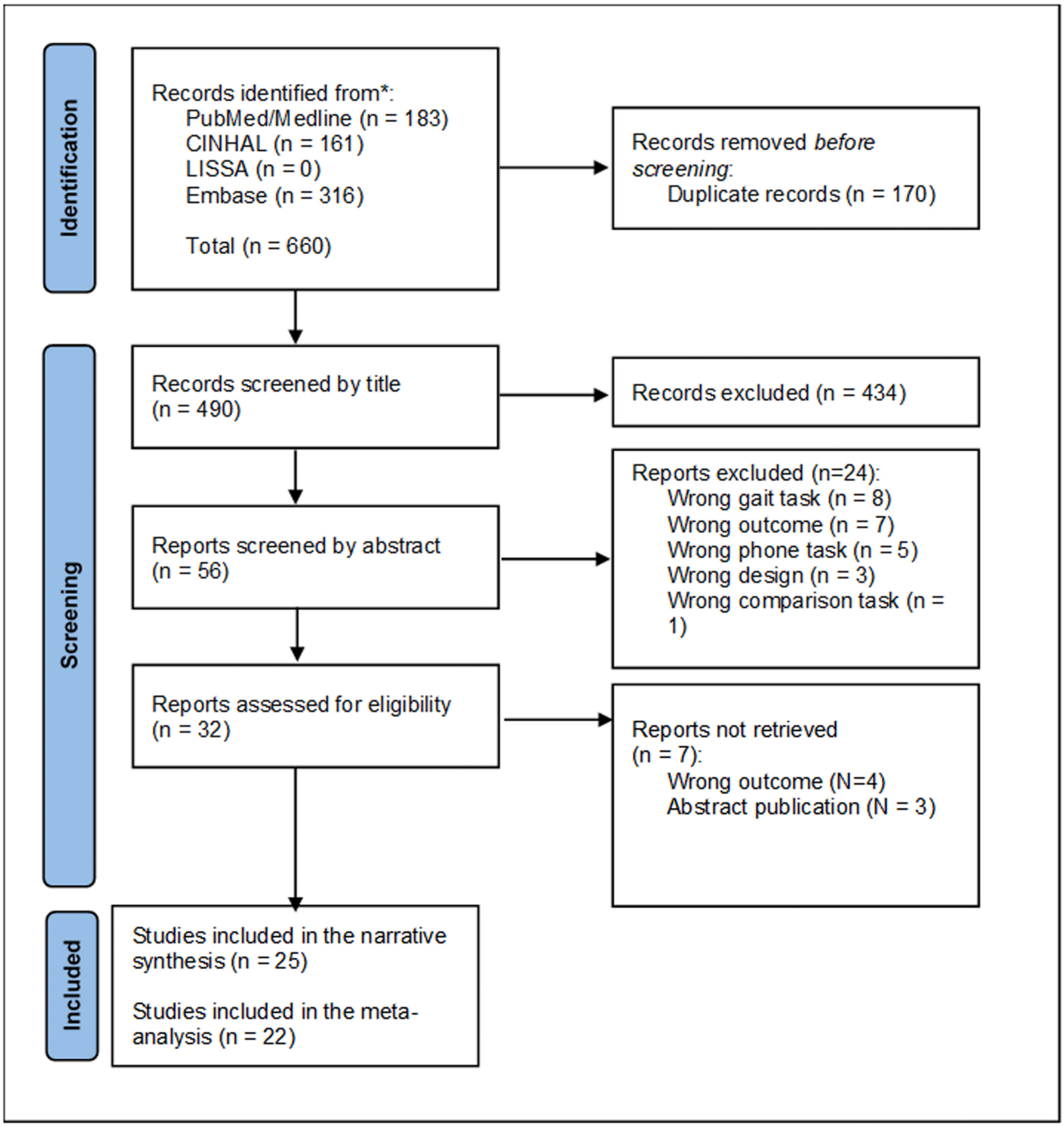

Fig. 1. PRISMA diagram showing the selection process for the systematic review.

to the following sections: primary author, year of publication, country, sample size, characteristics of the participants, study objective, setting, description of the single task, description of the dual-task, phone type, phone usage habits, gait assessment tool, outcomes, key findings, limitations, task prioritization. If there were disagreements, a third reviewer (ND) made the decision.

For the quantitative synthesis, data (mean or median, standard deviation (SD) or minimum, maximum, quartiles) were collected from the results sections and tables of the manuscripts. If necessary, the WebPlotDigitizer program (version 4.2) was used to extract data. If it was not possible to collect the data from the manuscript or missing data, the corresponding author was contacted once.

2.7. Quality of appraisal

Given the observational cross-sectional design of the included studies, many of the traditional quality assessment tools designed for randomized control trials were unsuitable. Therefore, the Downs and Black checklist was used to assess quality [24]. This tool is recommended and adaptable for all types of quantitative study designs [25]. The version modified by Smith et al., 2017 with a 15-point checklist was applied [26]. Given the importance of sample size on the validity of study results, the power item proposed in the original version of the scale was added [24]. The five subscales for the 16-point tool were evaluated: reporting (items 1–8), external validity (items 9–11), internal validity (items 12–15), and power (item 16). For all items, “yes” was scored 1, and “no” and “unable to determine” were scored 0. A total score (/16 points) was calculated for each study. Two authors (AVB and AR) independently appraised the studies in each of the domains of this tool. Disagreements during the quality assessments were discussed until a consensus was reached. A third reviewer (ND) provided the final decision if consensus was not reached.

2.8. Synthesis method

The data were quantitative, and an aggregative synthesis was appropriate for assessing the influence of dual-task conditions (texting + walking) versus single-task conditions (walking). For walking speed (main outcome), a meta-analysis was performed for all included studies, except for articles lacking data (e.g., mean and SD). After this first synthesis, a subgroups synthesis was realized based on age, walking tasks, and spatiotemporal parameters, only when two or more studies were included in the subgroup. Two analyses were performed: for all studies regardless of the quality of appraisal and for those with a Downs and Black’s quality score greater than or equal to 9. Means and SD of single task and dual-task conditions and the sample size of each study were extracted to perform the meta-analysis. Following Tufanaru et al. [27], the standardized mean difference (SMD) and 95 % confidence intervals (CI) were calculated. The SMD expresses the intervention effect in standard units rather than the original units of measurement. A SMD value of 0.2 represents a small effect, 0.5 a moderate effect, and 0.8 a large effect [28,29]. Heterogeneity between studies was assessed using I^2 tests. A fixed-effect model was applied in two cases: 1) if the I^2 values were ≤ 50 % (data were considered homogeneous); 2) if the number of studies included was less than five. A random-effect model was applied if the I^2 values were > 50 % (data were considered to have substantial heterogeneity). A p-value less than 0.05 was considered statistically significant.

3. Results

3.1. Characteristics of included studies

After the removal of duplicates, the initial search identified 490 articles. A total of 25 studies were included in the final review and the narrative synthesis, representing 1008 participants (Fig. 1).

All the studies recruited young adults (n = 25), and four studies recruited older adults [6,30–32]. The older groups comprised persons over 60 or 65 years, depending on the study. Three studies recruited a population with pathological conditions: multiple sclerosis (n = 2) [7,33] and obesity (n = 1) [34].

With the exception of five studies [6,35–38], most reported the frequency of smartphone use through the number of messages sent, the number of hours of use per day, or the number of months of use. One study collected the antecedents of accidents when using smartphones while walking [39].

Table 2 highlights the diversity of the texting tasks in the studies included (Table 2).

In nine studies [32,38,40–46], the participants were asked to answer general questions (for example, about general knowledge, general topics and favorite things, daily life, and habits). The participants had to copy a text displayed on the phone screen (n = 7 studies, e.g., a random sequence of words, three words, 20 words) [30,34–36,47–49], type sentence(s) read aloud (n = 4) [6,33,37,50], propose as many words as possible from a given category (n = 1) [31], or converse with someone (n = 1) [51]. In one study [40], the task was to reverse-text a word sent by the researcher. In three studies [38,51,52], the task involved typing random numbers between 0 and 20 in ascending or descending order, ordering seven single-digit numbers, or responding to a mental-arithmetic question. Two studies assessed two texting tasks with low or high cognitive load: general knowledge vs. reverse-texting a word [40], and the thumbs tapped on two buttons vs. a digit-ordering task [39]. In 36 % (n = 9) of the studies, there was no mention of whether or how the texting task was assessed Table 3 presents a synthesis of the data extraction.

In most studies (84 %, n = 21), the locomotor task was walking at normal speed over a specific distance and/or during a particular time. In four studies, the task of walking involved obstacles [36,37,44,45] — static, crossing the path, or of different heights (from 30 to 90 cm, depending on the study). Walking forward and backward [31] and walking quickly [51] were also proposed. When the study took place in an ecological setting only (n = 4), the walking task involved a footpath in three studies [6,40,52].

Four studies clearly reported an instruction according to task prioritization (texting or walking) in the procedure [35,38,47,53]. Prioritization instructions were not given in 16 studies and were not clearly reported in five studies (Table 3).

The walking speed was measured in all studies, but two did not report the data [39,40]. The data was retrieved for one of these studies [40]. Among the spatiotemporal gait parameters other than gait speed, the most frequently assessed were step or stride length (68 %, n = 17), cadence (52 %, n = 13), double support time (32 %, n = 8), and single support time (14 %, n = 3).

Compared with normal gait, the walking speed was decreased by a mean of 0.23 ± 0.12 m/s (young healthy: 0.19 ± 0.08 m/s; older: 0.42 ± 0.11 m/s) when texting. The texting task significantly altered other spatiotemporal parameters (Table 3): a decrease in step and stride length, a decrease cadence, a decrease in single support time, and an increase in double support duration.

3.2. Quality of appraisal of included studies

The quality scores were between 6 and 8 points/16 for eight studies [34,37–40,43,46,51], between 9 and 12/16 for 14 studies [6,30,32,35,36,41,42,44,45,48–50,52,53], and superior to 12/16 for three studies [31,33,47] (Table 4).

The main outcome of all the included studies was accurate (valid and reliable). The most common weaknesses concerned external validity, selection bias, and power (e.g., determining whether participants and places were representative of the entire population, if there was an adequate adjustment for confounding in the analyses from which the main findings were drawn, and if the study had a sufficient sample size).

Table 2
Description of the phone texting tasks.

Author, year	Texting tasks	Task description	Texting task assessment
Caramia, 2017	*Task 1: While using an instant messaging app, answering to general knowledge questions asked by the experimenter at the other end (Low Cognitive Load);* *Task 2: While using an instant messaging app, by reverse texting a word sent by the experimenter at the other end (High Cognitive Load).*	Answering general questions Reverse text a word	No
Agostini, 2015	*To type a message describing their own activities on the day before the test.*	Answering general questions	Typing speed (number of characters per minute)
Crowley, 2019	*To type answers to the questions covering the topics of sport, music, film, hobbies, food, and study program.* (e.g. *“What is your favorite music genre and artist? Why is this genre your favorite? Why is this your favorite artist, give me three reasons? What is your favorite song by your favorite artist? How often do you listen to their music? What is your least favorite music genre?”*	Answering general questions	Number of characters per second
Parr, 2014	*To respond to a previously unknown question by entering the answer into their phone's text messaging system.*	Answering general questions	Number of characters typed during the texting condition
Strubhar, 2015	*The researchers sent the participants a different standardized question. When the participants were ready to respond to the question, they began texting and walking.*	Answering general questions	Mean number of errors and characters per second
Chen, 2018	*Short questions with specific answers* (e.g., *What is the third month of the year?). Participants were asked to respond to the message by texting back their answers.*	Answering general questions	No
Licence, 2015	*Responding to standardized texting questions.*	Answering general questions	No
Uchiyama, 2012	*Text message with answers to questions:* – *What did you eat for lunch?* – *What is your primary recent concern?* – *What do you first do in the morning after getting up?* – *What is your biggest mistake to date?* – *Please express your character using a single word* – *What enrichment lessons have you had just before now?*	Answering general questions	No
Prupetkaew, 2019	*Answering questions by texting. The questions presented for all cognitive tasks were randomly chosen from a similar topic regarding their daily activities* (e.g. *What are your favorite foods?), with different questions asked to prevent learning.*	Answering general questions	Response rate and accuracy (number of correct responses versus the total number of answers provided)
Plummer, 2015	*Application, “My Speed,'' was used for the texting task. To type the phrase that appeared on the screen as quickly and as accurately as possible into the textbox below the phrase.*	Copying text	Texting speed (characters per minute), error rate (%), and duration (s)
Brennan, 2020	*To type a copy of a passage that was sent to them* via *text message with the autocorrect function turned off.*	Copying text	No
Brennan, 2021	*To type a copy of a message without using the backspace key to correct mistakes.*	Copying text	Texting accuracy (% error, number of characters incorrectly typed) and speed (characters per second)
Krasovsky, 2021	*To copy the words that appeared on screen (20 words on each screen).*	Copying text	Number of letters typed
Krasovsky, 2018	*Three words in Hebrew sentences describing simple activities/states* (e.g. *“I ate pizza,” “It's cold today”) were presented in white text on the top of the screen and the user was requested to copy them as quickly and accurately as possible.*	Copying text	Mean texting speed (characters per minute) and texting accuracy (number of single-character edits required to match typed with presented text)
Lim, 2020	*An application software provided a random sequence of words with the same difficulty. The participants were asked to copy as many words as accurately as possible.*	Copying text	Texting speed (word per minute) and accuracy of texting (%, correct words) in a fixed time duration
Pau, 2018	*To digit a number of words displayed on the screen after random selection by a dedicated application (Fast Type ver.1.55, http://frozened.me/).*	Copying text	Texting performance (ratio between the number of words correctly typed by the number of those displayed by the application during the trial time)
Schabrun, 2014	*Typing the passage ‘the quick brown fox jumps over the lazy dog’.*	Typing a sentence read aloud	Number of errors (% total words texted) and the average number of correct words texted/minute
Lopresti-Goodman, 2012	*In order to ensure uniformity in the message being texted*	Typing a sentence read aloud	No

(continued on next page)

Table 2 (*continued*)

Author, year	Texting tasks	Task description	Texting task assessment
	across all participants, individuals in the texting condition were provided with sentences to write before being asked to turn around. The sentences ranged in length from 15 to 21 (M= 18.1, SD = 1.41) characters, including spaces, and were simple in meaning (e.g. 'I have a paper cut' or 'The jar was broken').		
Alapatt, 2020	*Texting the message "Good morning Harry".*	Typing a sentence read aloud	The spelling accuracy and completion of the message. Texting errors: % of participants with incomplete or incorrect texts.
Sirhan, 2018	*The examiner read aloud a sentence constructed from exactly 20 characters. Using their own mobile device, participants were instructed to text each sentence using their usual typing method on the WhatsApp mobile application and send the message (sentence) to the examiner's mobile phone.*	Typing a sentence read aloud	Texting accuracy (%): percentage of grammatical errors. Texting duration (s): overall amount of time to text and send the five sentences.
Jian, 2018	*Mental arithmetic tasks by text message: to text and respond to the mental-arithmetic conversation.*	Arithmetic	No
Kim, 2020	*To [type numbers] in ascending or descending direction, starting with a random number between 0 and 20. The ascending or descending direction and random number were determined using the website randomization.com (http://www.randomization.com).*	Arithmetic	No
Tian, 2018	*Task 1: Two thumbs tapped on two large buttons* *Task 2: Digit ordering task (7 single-digit random numbers)*	Arithmetic	Speed performance, accuracy performance (how similar the ordered number sequence was to the correct sequence), increase of key presses (% number of actual key presses compared to the number minimally needed)
Crowley, 2021	*The protocol used "structured text messaging and semi-structured mobile phone conversations".*	Conversing	No
Belur, 2020	*To type list as many words as they could from a given category. New categories were given for each trial and were randomized across participants.*	Fluency	Number of correct words per second

3.3. Meta-analysis

Twenty-two of the 25 studies were included in the meta-analysis. One study was excluded because the values relative to the single task were not reported [39]. Two studies were excluded because they did not report the SD value of spatiotemporal parameters [6,43]. Results for the two analyses (regardless the quality of appraisal – $n = 22$, and then only the studies with a Downs and Black's quality score greater than or equal to 9 – $n = 17$) are given in Table 5.

For the walking speed, the datasets were analyzed for all studies ($n = 22$) and separately for three subgroups: under 60, over 60, and multiple sclerosis. The only study involving individuals with obesity was excluded from the subgroups analysis [34]. In the case of young subjects (< 60 years), the datasets were analyzed for normal gait (laboratory and ecological conditions) and gait with obstacles. Meta-analysis was also conducted for six secondary outcomes: stride length, step length, double support phase, single support time, cadence.

3.3.1. Effects of texting task on gait speed

3.3.1.1. All studies. The results highlighted a large effect for dual-task on walking speed compared to single task in all studies and synthesis based on the Downs and Black checklist score ($\text{SMD} \geq 1.33$) (Table 5, Fig. 2).

3.3.1.2. Study settings. The heterogeneity of the studies was greater in ecological settings ($I^2 \geq 77$ %) than in laboratory settings ($I^2 \geq 49$ %). In both settings, the effect of texting on gait velocity was large ($1.01 \leq \text{SMD} \leq 1.75$, Table 5).

3.3.1.3. Walking at normal speed in sub-group analyses. Heterogeneity among data was substantial for healthy young subjects ($I^2 = 69$ % and 51 %, $p < 0.001$ and $p = 0.008$), older persons ($I^2 = 82$ %, $p = 0.001$), and persons with multiple sclerosis ($I^2 = 71$ %, $p = 0.062$). The effect of texting task on gait velocity was large in healthy young subjects ($1.28 \leq \text{SMD} \leq 1.39$), older persons ($\text{SMD} = 1.74_{[1.36;\ 2.11]}$), and persons with multiple sclerosis ($\text{SMD} = 0.98_{[0.66;\ 1.30]}$, Table 5, Fig. 3).

3.3.1.4. Walking at normal speed with obstacles. Only one study had a quality score ≥ 9/16; thus, no meta-analysis was conducted based on quality score. Overall, data were considered homogeneous (I^2=35 %, $p = 0.200$). The effect of dual task was large, with a SMD of $1.47_{[1.12;\ 1.81]}$.

3.3.2. Effects of the texting task on other spatiotemporal parameters

For step and stride length, the data were considered to have substantial heterogeneity ($I^2 \geq 79$ %, $p < 0.001$). When the analysis was conducted on the best quality studies, the heterogeneity decreased ($I^2 \geq 68$ %, $p < 0.019$). The effect of dual-task was large for the step and stride length parameters ($\text{SMD} \geq 1.11$, Table 5, Fig. 4).

When the cadence parameters were analyzed, the results showed homogeneous data (2 % $\leq I^2 \leq$ 8 %, $p > 0.358$), and the effect of dual task was large, with an SMD higher than 1.08 (Table 5, Fig. 5).

The duration of double support and single support were characterized by a substantial heterogeneity ($I^2 \geq 56$ %, $p < 0.044$) that was reduced after selecting studies on the quality score (17 % $\leq I^2 \leq$ 56 %, $p > 0.023$). The effect of dual-task was large, with 95 % CI (Table 5, Fig. 6).

4. Discussion

4.1. Interpretation of the main results

Texting while walking is a common situation in daily life. In this analysis, the 25 studies included in the narrative synthesis highlighted a

Table 3
Data extraction of the reports included in the narrative synthesis.

Setting	1st author, year, country	Population (N)	Age (years)	Single task description	Dual task	Task prioritization	Phone usage habits	Tool used for gait speed measurement	Gait velocity – single task (mean, SD)	Gait velocity – dual task (mean, SD)	p-value	Other key results	Limitations, comments
Healthy subjects (<60 years)													
Ecological	*Caramia, 2017, Italy*	Healthy (10)	21–23	Walking on pedestrian passage (normal speed 21 s max) - 1 trial - 14 m	Texting	No	> 2 h per day	Inertial captor (lumbar)	1.69 (0.03) m/s	1.57 (0.04)	< 0.001	Increase step time ($p < 0.05$); Decrease step length, stride frequency ($p < 0.05$)	No sample size calculated, small group, no data description about means and SD, no post hoc p-value between tasks
	Crowley, 2021, Denmark	Healthy (20)	27 (5.5)	Walking (normal and *fast* speed) - 12 trials - 80 m	Texting	No	Own mobile phone for more than one month (regular use >1 h per day)	Accelerometer	1.65 (0.17) m/s	1.42 (0.18)	< 0.001	Increase coefficient variation ($p < 0.001$)	No sample size calculated, no information about phone type and texting task, no fixed speed, no texting task information
	Jiang, 2018, China	Healthy (28)	20.6 (2.23)	Walking on pedestrian passage (normal speed 21 s max) - 1 trial - 14 m	Texting	Not indicated	Use mobile phones with greater frequency than other groups	2D camera	1.46 (0.19) m/s	1.36 (0.16)	0.01	Increase initiate crossing time ($p < 0.001$)	No sample size calculated, low traffic volume, no personal phone
Ecological and laboratory	*Plummer, 2015, USA*	Healthy (31)	22.5 (2.1)	Walking (normal speed) - 2 trials - 30 m	Texting	Yes (gait or texting)	> 10 messages per day.	Inertial captors	Laboratory: 1.30 (0.12) m/s; Ecological: 1.12 (0.15)	Texting priority: Laboratory: 1.09 (0.17); Ecological: 0.98 (0.17)	< 0.001, NS between laboratory and ecological settings	NA	No sample size calculated, texting no real task for standardized task
Laboratory	*Agostini, 2015, Italy*	Healthy (18)	20–30	Walking (normal speed) - during 3 min - 15 m	Texting	No	Smartphone use each day and 2 months of experience with their current mobile phone for > 2 months	Foot-switches	1.30 (0.12) m/s	1.17 (0.10)	< 0.001	Decrease cadence ($p < 0.001$), stride length ($p < 0.001$); Increase double support ($p < 0.001$), stride to stride variability ($p = 0.008$)	No information about phone habits, sample size not calculated
	Brennan, 2020, USA	Healthy (14)	19.64 (1.39)	Walking (normal speed) - 5 trials - 10 m	Texting	No	Not reported	3D motion analysis	1.41 (0.13) m/s ?	1.04 (0.09)	< 0.001	Decrease stride length ($p < 0.001$)	No sample size calculated, no phone type information and phone usage habits
	Brennan, 2021, USA	Healthy (14)	19.64 (1.39)	Walking (normal speed) - 5 trials - 10 m	Texting	Yes (texting or gait)	Not reported	3D motion analysis	1.04 (0.09) m/s	Texting priority: 0.91 (0.14); walking priority: 1.09 (0.14)	0.001 for texting priority; walking priority: NS	Decrease stride length ($p < 0.001$)	No sample size calculated, small group, no random order between single and dual task
	Crowley, 2019, Denmark	Healthy (10)	24.7 (4.4)	Walking (normal speed or rapid speed) - 2 trials - 80 m	Texting	No	Regular mobile phone use and the use of their current mobile phone for > 1 month	Accelerometer	1.4 (0.2) m/s / Rapid: 1.7 (0.2)	1.3 (0.2) / Rapid 1.5 (0.2)	$p < 0.05$	Decrease cadence, stride length ($p < 0.05$); Increase double support time ($p < 0.05$)	No sample size calculated, small sample size, accuracy Physilog

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Table 3 (*continued*)

Setting	1st author, year, country	Population (N)	Age (years)	Single task description	Dual task	Task prioritization	Phone usage habits	Tool used for gait speed measurement	Gait velocity – single task (mean, SD)	Gait velocity – dual task (mean, SD)	p-value	Other key results	Limitations, comments
	Kim, 2020, Korea	Healthy (36)	24.69 (1.94)	Walking (normal speed) - 3 trials - 20–4.6 m	Texting	Yes (texting)	> 6 months	GAITRite	129 (18.33) cm/s	Both hands: 101.84 (15.84); one hand: 102.88 (18.40)	< 0.001	Decrease cadence, step length, stride length, swing time (%), single support, normalized velocity ($p < 0.001$); Increase stance time, double support time ($p < 0.001$)	No information about phone habits, no sample size calculated
	Krasovsky, 2021, Israel	Healthy (29)	26 (4.18)	Walking (normal speed) - 30 m	Texting	No	> 1 year phone experience	Inertial captors	1.24 (0.24) m/s	0.93 (0.23)	< 0.001	Decrease stride length, stride time ($p < 0.001$); Increase gait speed variability ($p < 0.001$)	One subject excluded due to technical issue, no random task order, text format different between tasks
	Parr, 2014, USA	Healthy (30)	20 (2)	Walking (normal speed), 5 trials - 8 m	Texting	No	Sending between 50 and 1000 text messages per week (mean: 379 +/−303)	3D motion analysis	1.2 m/s	1.0	< 0.001	Increase step width ($p < 0.001$), stance time ($p < 0.001$), double support ($p < 0.001$); Decrease toe clearance ($p < 0.001$), step length ($p < 0.001$), cadence ($p < 0.001$), swing time ($p < 0.001$)	No sample size calculated, data without SD. No limitation section
	Schabrun, 2014, Australia	Healthy (26)	29 (11)	Walking (normal speed) - 3 trials - 8.5 m	Texting	Not indicated	> 30 min texting per day, > 3 months experience	3D motion analysis	1.33 (0.15) m/s	1.01 (0.17)	< 0.001	Decrease stride length ($p < 0.001$), stride frequency ($p < 0.0002$)	The subjects practiced writing the text with the same message before tests. No sample size calculated
	Strubhar, 2015, USA	Healthy (32)	24 (18 – 40)	Walking (normal speed) – 3 trials – 4 m	Texting	No	Familiar with texting and own a smartphone	GAITRite	129.81 (12.85) cm/s	106.34 (12.16)	0.001	Decrease cadence and step length ($p < 0.001$); Increase double support % cycle ($p = 0.002$)	No sample size calculated, phone type not described
	Tian, 2018, China	Healthy (22)	20–27	Walking (normal speed) – 6 trials – 20 m	Texting	Unclear	Experienced walking with phone task, > 1 year used	Inertial captors	No values reported	No values reported	< 0.001	Decrease stride length ($p < 0.001$); Increase stride time and stride time variability ($p < 0.001$)	No detailed data (mean, SD), no exclusion criteria, no sample size calculated
Walking with obstacle in laboratory setting	*Chen, 2018, USA*	Healthy (10)	21.5 (2.1)	Walking with obstacle crossing (normal speed) – 5 trials – 15 m	Texting	No	> 1 year experience with smartphone, > 5 messages per day (mean: 127)	3D motion analysis	1.22 (0.06) m/s	1.11 (0.09)	< 0.05	Increase foot-obstacle clearance ($p < 0.05$), ML CoM crossing ($p < 0.05$); Decrease foot placement leading foot ($p < 0.05$),	Small group, same question, no prioritization task

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Table 3 (*continued*)

Setting	1st author, year, country	Population (N)	Age (years)	Single task description	Dual task	Task prioritization	Phone usage habits	Tool used for gait speed measurement	Gait velocity – single task (mean, SD)	Gait velocity – dual task (mean, SD)	p-value	Other key results	Limitations, comments
												Peak forward vCOM ($p < 0.05$)	
	Lopresti-Goodman, 2012, USA	Healthy (25)	Not reported	Walking (normal speed) with different doorway frame (40–90 cm) – 3 trials per condition – 5 m	Texting	Not indicated	Not reported	2D camera	0.97 (0.14) m/s	0.71 (0.14)	< 0.001	NA	No sample size calculated, small group, no statistics description. It is not the same group with the single and dual-task conditions. Two different groups for each test
	Licence, 2015, UK	Healthy (30)	18 – 50	Walking with obstacles crossing – 1 trial – Distance not mentioned	Texting	No	own mobile phone for more than one month	3D motion analysis	0.78 (0.1) m/s	0.61 (0.1)	< 0.001	Decrease step length, step frequency ($p < 0.001$); Increase double support ($p < 0.001$)	1 trial, no information about phone habits, no information about texting task, no limitations part in the discussion, no sample size calculated
	Uchiyama, 2012, Japan	Healthy (20)	Men: 20.3 (0.9) / Women: 19.4 (3.3)	Walking (normal speed), and walking with an obstacle (30 and 50 cm) - 3 trials - 10 m	Texting	Yes (texting)	Not reported	Walkway gait parameters (MG-1000 ANIMA)	Normal: 107.70 (13.41) cm/s; Obstacle 30 cm: 96.09 (10.90); Obstacle 50 cm: 89.94 (11.53)	Normal: 93.95 (15.10); Obstacle 30 cm: 85.44 (13.49); Obstacle 50 cm: 81.84 (11.60)	< 0.001	Decrease cadence ($p < 0.01$), step length ($p < 0.001$). Stance phase, double phase (NS)	No limits section, no sample size calculated, small group, no exclusion criteria, no use phone habits
Older subjects (>60 years)													
Ecological	*Alapatt, 2020, Australia*	Healthy (Group 1 (50); Group 2 (52); Group 3 (55); Group 4 (51); Group 5 (100))	Group 1: 20–29; Group 2: 30–39; Group 3: 40–49; Group 4: 50–59; Group 5: > 60	Walking (normal speed) - 10 m (on a pedestrian walkway of the bridge)	Texting	No	Not reported	Chronometer	Group 1: 1.5 m/s; Group 2: 1.49; Group 3: 1.53; Group 4: 1.47; Group 5: 1.42	Group 1: 1.35; Group 2: 1.32; Group 3: 1.28; Group 4: 1.07; Group 5: 1.00	< 0.001 between single and dual task; < 0.001 between groups	NA	No information about phone use (usual texting activity), no sample size calculated, no SD values, bias control (BMI, shoes, cognitive factors)
Laboratory and ecological	*Krasovsky, 2018, Israel*	Young (30), older (30)	Young: 27.8 (84.4); Older: 68.9 (3.9)	Walking (normal speed) - 1 min - 30 m	Texting	No	Use a smartphone for more than 1 year	Accelerometer	Young indoor: 1.45 (0.23) m/s; Young outdoor: 1.48 (0.20); Older indoor: 1.33 (0.21); Older outdoor: 1.32 (0.26)	Young indoor: 1.24 (0.25); Young outdoor: 1.28 (0.26); Older indoor: 1.03 (0.25); Older outdoor: 1.00 (0.24)	Young: < 0.05; Older: < 0.05; < 0.05 between groups	Decrease stride length ($p < 0.05$); Increase stride time, variability NS	Sample size not calculated
Laboratory and ecological	*Prupetkaew, 2019, Thailand*	Young (12), older adults (12)	Young: 22.7 (1.8); Older: 73.5 (5.6)	Walking (normal speed) - 3 trials - 10 m	Texting	No	> 200 messages per month, 2 months	Accelerometer	Young labo: 1.30 (0.17) m/s; Young ecological: 1.30 (0.23); Older labo: 1.29 (0.17); Older	Young labo: 1.02 (0.18); Young ecological: 1.03 (0.19); Older labo: 0.73 (0.21); Older	Young: < 0.05; Older: < 0.05; < 0.05 between groups	Decrease step length, cadence ($p < 0.05$); Increase longer step time ($p < 0.05$); NS between environment	Sample size not calculated, small, unclear p value

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Table 3 (*continued*)

Setting	1st author, year, country	Population (N)	Age (years)	Single task description	Dual task	Task prioritization	Phone usage habits	Tool used for gait speed measurement	Gait velocity – single task (mean, SD)	Gait velocity – dual task (mean, SD)	p-value	Other key results	Limitations, comments
									ecological: 1.28 (0.12)	ecological: 0.75 (0.14)			
Laboratory	*Belur, 2020, USA*	Group 1: young (18–30 y – N = 24), Group 2: older (60–75 y – N = 26)	Group 1: 22.79 (3.12); Group 2: 68.88 (4.16)	Walking forward and backward - 3 trials – 5.75 m	Texting	No	Having experience using the smartphone's texting features for at least 6 months	GAITRite	Group 1: 120.1 (18.8) cm/s; Group 2: 123.4 (21.4)	Group 1: 98.3 (18.7); Group 2: 83.1 (29.3)	$p = 0.005$; between groups $p = 0.029$	Decrease cadence ($p < 0.015$), stride length ($p < 0.001$)	Short distance, texting experience not described, absence of cognitive status, texting experience
Subjects with obesity													
Laboratory	*Lim, 2020, USA*	OB: obese group (16), NW: normal weight group (16)	OB: 27.3 (1.5), NW: 26.6 (1.0)	Walking (normal speed, imposed frequency: −10 % or +10 % of normal frequency) - 60 s - 2 trials - 8 m	Texting	No	> 1 year phone experience	Inertial captors	NW: 1.27 (0.03) m/s; OB: 1.22 (0.03)	NW: 1.16 (0.03); OB: 1.09 (0.03)	< 0.01 (group comparison: NS)	Decrease cadence, single support, stride length ($p < 0.01$); Increase double support, stance phase and lateral step variability ($p < 0.01$)	No sample size calculated, no random order, turn in the gait task, frequency gait consign
Subjects with multiple sclerosis													
Laboratory	*Pau, 2018, Italy*	Group 1: multiple sclerosis (54); Group 2: healthy (40)	Group 1: 39.8 (10.7); group 2: 41.3 (10.4)	Walking (normal speed) - 1 trial - 20 m	Texting	Not indicated	Regular phone use	Inertial captors	Group 1: 1.07 (0.28) m/s; Group 2: 1.24 (0.22)	Group 1: 0.86 (0.26); Group 2: 0.94 (0.20)	< 0.001; between groups: 0.010	Decrease stride length ($p < 0.001$), cadence ($p < 0.001$), swing phase ($p = 0.004$); Increase stance phase ($p = 0.004$) and double support ($p = 0.004$)	One trial per condition, moderate motor impairments, no sample size calculated
Laboratory	*Sirhan, 2018, Israel*	Group 1: multiple sclerosis (30); Group 2: healthy (15)	Group 1: 38.8 (5.7); Group 2: 37.4 (6.3)	Walking (normal speed) - 1 trial - 30 m during 2 min	Texting	No	Capacities of using a mobile device	Accelerometer	Group 1: 0.68 (0.21) m/s; Group 2: 1.19 (0.14)	Group 1: 0.41 (0.16); Group 2: 0.98 (0.10)	< 0.001; between groups 0.041	Decrease cadence ($p < 0.001$), stride length ($p < 0.001$), single support ($p < 0.001$), swing phase ($p < 0.001$); Increase step duration ($p < 0.001$), stance phase ($p < 0.001$) double support ($p < 0.001$)	One trial per condition, no information about phone habits, no sample size calculated, no assessment of fine motor capacities

SD = Standard deviation; NS = non significant, NA = not applicable.

Table 4
Quality of appraisal: Downs and Black checklist results for each study.

First author, year		Caramia, 2017	Crowley, 2021	Jiang, 2018	Plummer, 2015	Agostini, 2015	Brennan, 2020	Brennan, 2021	Crowley, 2019	Kim, 2020	Krasovsky, 2021	Parr, 2014	Schabrun, 2014	Strubhar, 2015	Tian, 2018	Chen, 2018	Licence, 2015	Lopresti-Goodman, 2012	Uchiyama, 2012	Alapatt, 2020	Krasovsky, 2018	Prupetkaew, 2019	Belur, 2020	Lim, 2020	Pau, 2018	Sirhan, 2018
Reporting																										
1	Is the hypothesis/aim objective of the study clearly described?	-	-	-	+	-	+	+	+	-	+	+	+	+	-	+	+	?	-	-	+	+	+	+	+	+
2	Are the main outcomes to be measured clearly described in the Introduction or Methods section?	+	+	-	+	+	-	+	+	+	-	+	-	+	+	+	+	+	-	+	+	+	+	+	+	-
3	Are the characteristics of the patients included in the study clearly described?	-	+	+	+	+	+	+	+	+	+	+	+	+	?	+	-	-	-	+	+	+	+	+	+	+
4	Are the interventions of interest clearly described? i.e. walking task and secondary task	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5	Are the distributions of principal confounders in each group of subjects to be compared clearly described?	-	+	+	+	+	+	+	+	+	+	-	+	+	?	+	-	-	+	-	+	+	+	+	+	+
6	Are the main findings of the study clearly described?	-	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+
7	Does the study provide estimates of the random variability in the data for the main outcomes?	-	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+
8	Have actual probability values been reported (e.g. 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+
External validity																										
9	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	-	-	-	-	-	?	-	-	-	+	-	+	+	-	?	+	?	-	+	+	+	+	-	+	+
10	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?	?	?	+	+	+	-	+	-	-	-	-	?	-	-	+	?	?	-	+	?	-	?	-	+	+
11	Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?	+	+	+	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	+	-	-	-	-
Internal validity																										
12	Were the statistical tests used to assess the main outcomes appropriate?	+	+	-	-	+	-	+	+	+	+	-	+	-	-	-	-	?	-	+	+	+	+	-	-	+
13	Were the main outcome measures used accurate (valid and reliable)?	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Internal validity (confounding) (selection bias)																										
14	Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?	+	?	+	+	+	+	+	?	+	+	-	?	?	+	?	?	+	?	+	?	?	?	-	+	+
15	Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	-	-	-	+	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+
Power																										
16	Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?	-	-	-	+	-	-	?	-	-	+	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-
Total score																										
Score / 16		**7**	**8**	**10**	**14**	**12**	**9**	**12**	**11**	**12**	**12**	**7**	**10**	**10**	**5**	**10**	**8**	**7**	**6**	**12**	**11**	**12**	**13**	**8**	**12**	**13**

Table 5
. Meta-analysis results for all studies and studies with a Downs and Black's quality score greater than or equal to 9.

		All studies		**Studies with a Mc Master score ≥ 9/16**	
Conditions	**Parameters**	**I^2 (p-value)**	**SMD (95 % CI)**	**I^2 (p-value)**	**SMD (95 %CI)**
All	Velocity	71 % ($p < 0.001$)	1.45 [1.23;1.68]	60 % ($p < 0.001$)	1.33 [1.12;1.55]
Laboratory normal gait		49 % ($p = 0.004$)	1.40 [1.18;1.61]	53 % ($p = 0.005$)	1.37 [1.22;1.52]
Ecological normal gait		91 % ($p < 0.001$)	1.75 [0.95;2.56]	77 % ($p = 0.001$)	1.01 [0.76;1.26]
Young adults, normal gait		69 % ($p < 0.001$)	1.39 [1.13;1.66]	51 % ($p = 0.008$)	1.28 [1.06;1.51]
Young adults, gait with obstacle		35 % ($p = 0.200$)	1.47 [1.12;1.81]	Only 1 study	
Older adults		82 % ($p = 0.001$)	1.74 [1.36;2.11]	None	
Persons with multiple sclerosis		71 % ($p = 0.062$)	0.98 [0.66;1.30]	None	
All	Step length	85 % ($p < 0.001$)	1.11 [0.48;1.73]	71 % ($p = 0.019$)	1.73 [1.02;2.44]
	Stride length	79 % ($p < 0.001$)	1.27 [0.93;1.61]	68 % ($p < 0.001$)	1.15 [0.87;1.42]
	Cadence	8 % (0.358)	1.08 [0.94;1.22]	2 % (0.422)	1.16 [1.00;1.32]
	Double support	89 % ($p < 0.001$)	-0.99 [−1.56;−0.42]	56 % ($p = 0.023$)	-0.71 [−1.00;−0.42]
	Single support	56 % ($p = 0.044$)	-1.29 [−1.61;−0.97]	17 % ($p = 0.312$)	-1.21 [−1.59;−0.83]

SMD: standardized mean difference; CI: confidence interval.

systematic decrease in walking speed, step and stride length, and cadence, and an increase in the double support phase during the dual-task condition compared to walking only. The effects of texting on gait parameters were observed for young adults, older people, obese people, and patients with multiple sclerosis, and the meta-analysis revealed that the effects were significant. Studies including young adults were more numerous which allowed to dissociate the meta-analysis through setting (laboratory or ecological) and walking task (normal walking or walking through obstacles). However, the quality of the studies was heterogeneous (poor to good).

The mean decrease in walking velocity induced by writing a text message (−0.23 ± 0.12 m/s, −19 %) was higher than the minimal

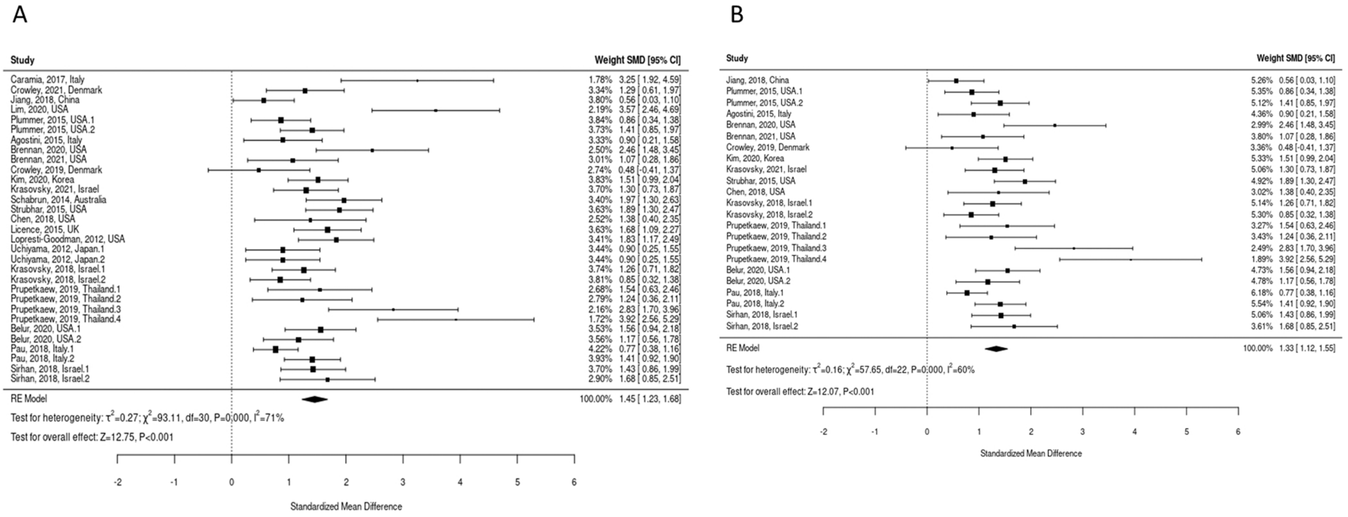

Fig. 2. Forest plot showing the effect of a dual-task on walking speed for all studies included in the meta-analysis. Plot A represents results without selection, and plot B represents the results from selected studies (score Downs and Black ≥9/16). RE = random-effect model. SMD = standardized mean difference.

detected change value for the walking speed parameter [19]. Whatever the population, the walking slowdown was greater than 7 %; the rate described by Crowley et al., 2016 in healthy adults [16]. Older adults seem to have greater difficulties when writing a text message while walking than young adults. Indeed, the decrease in gait velocity for persons over 60 (−0.42 ± 0.10 m/s, −32 %) was more important than the decrease in young adults. Moreover, for the older groups, the degradation in walking speed was impacted by the texting task more than by mental tracking or verbal fluency dual tasks (0.25 m/s) [54]. The additional impact of the smartphone task on walking degradation could be explained by the conceptual model of Stavrinos et al., 2018 [55]: the texting and walking tasks induce visual, aural, motor, and cognitive distraction. Hence, the prioritization conflict is more complex and challenging for the human system than a cognitive dual task.

In single task conditions, the gait velocity threshold of 1 m/s is considered critical for identifying frailty in older persons [56]. While young adults in the studies were always above this threshold in single and dual tasks, older people often had a speed below 1 m/s in the "texting + gait" task. This figure is clinically meaningful because this slowing of walking is associated with increased gait instability in a group that already has a greater risk of falls [57]. The threshold of 1 m/s was also passed in people with multiple sclerosis. Our meta-analysis showed that in this group, texting's effect on walking speed was less important than in the other groups but was still very large. In this population, the dual-task assessment is relevant because the difference between single and dual-task performance during walking seems predictive of fall risk [58]. Therefore, proposing a daily life-based task such as texting while walking should help to assess the risks better. Given the few studies in our analysis that include this population, new studies are needed before further recommendations can be made.

The decrease in walking speed during a dual-task is usually considered a result of the cognitive or motor cost of the additional task. Reducing walking speed might also be considered a compensatory behavior to ensure safe walking [55]. However, a reduced walking speed is challenging for postural control and stability [57]. Our meta-analysis showed that texting largely affects spatial gait parameters. By reducing step and stride length and increasing double support duration, individuals can improve postural stability and offset the effect of decrease in walking speed that leads to instability and falls [57,59]. However, Crowley et al., 2016 [60] demonstrated that the dual-task of walking and texting increases variability in the gait cycle despite adaptive strategies, reflecting multisystemic impairments for efficiently realizing the dual task [61]. Thus, adapting spatiotemporal parameters during texting and walking seems insufficient for providing a safety walking without postural instability.

Overall, texting during walking appears to be an irresolvable risk situation, and the texting is inherently prioritized. This conclusion is confirmed by the significant effect of texting on every gait parameter computed in the meta-analysis. For motor aspects, merely holding the phone induces postural perturbation by modifying the multi-segmental posture to stabilize the phone relative to the head and stabilizing the upper limbs to facilitate the fine motor skills of the hands [50]. Texting also inherently directs visual attention toward the phone, decreasing awareness of external cues and self-motion [32]. Finally, this smartphone task monopolizes cognitive resources. Plummer et al., 2015 [62] showed that in the absence of instructions, young adults prioritize the texting task, although people were capable of prioritizing gait when the instruction was given [35,62]. Despite the importance of prioritization, only four of the analyzed studies explicitly indicated whether a task had to be prioritized [35,38,47,53].

However, Plummer et al.'s 2015 results varied depending on the environment: the participants prioritized texting in the low-distraction environment (e.g., a laboratory), but the attention was more equally distributed in the ecological setting. It could be assumed that participants probably prioritized texting over walking in the indoor context more than in the less safe and more attention-demanding outdoor setting. Indeed, when studies with quality scores ≥ 9/16 were considered, the meta-analysis showed a larger effect for the dual-task condition in laboratory settings than in ecological settings. Furthermore, Krasovsky et al., 2018 [30] highlighted that the outdoor ecological situation increased the differences between people of different ages and the walking variability.

In daily life, smartphones are used while walking in various conditions, including over a cluttered path. Avoiding an obstacle could have increased the risk associated with texting, considering that it is a complex task requiring visual, motor, and cognitive resources. Nevertheless, this is not what the meta-analysis showed, as the effects of texting during walking were similar regardless of obstructions on the path. However, studies on walking with obstacles use other specific parameters such as stumbles or contact between the foot and the obstacles [46,63]. None of the studies involving obstacles were conducted in an ecological setting, probably for reasons of safety in the experimental setup.

The analysis showed that most studies were conducted in a laboratory setting. However, the dangers associated with texting while walking relate primarily to the outdoors, where people have to accommodate extreme sensory stimulation and various demands on their

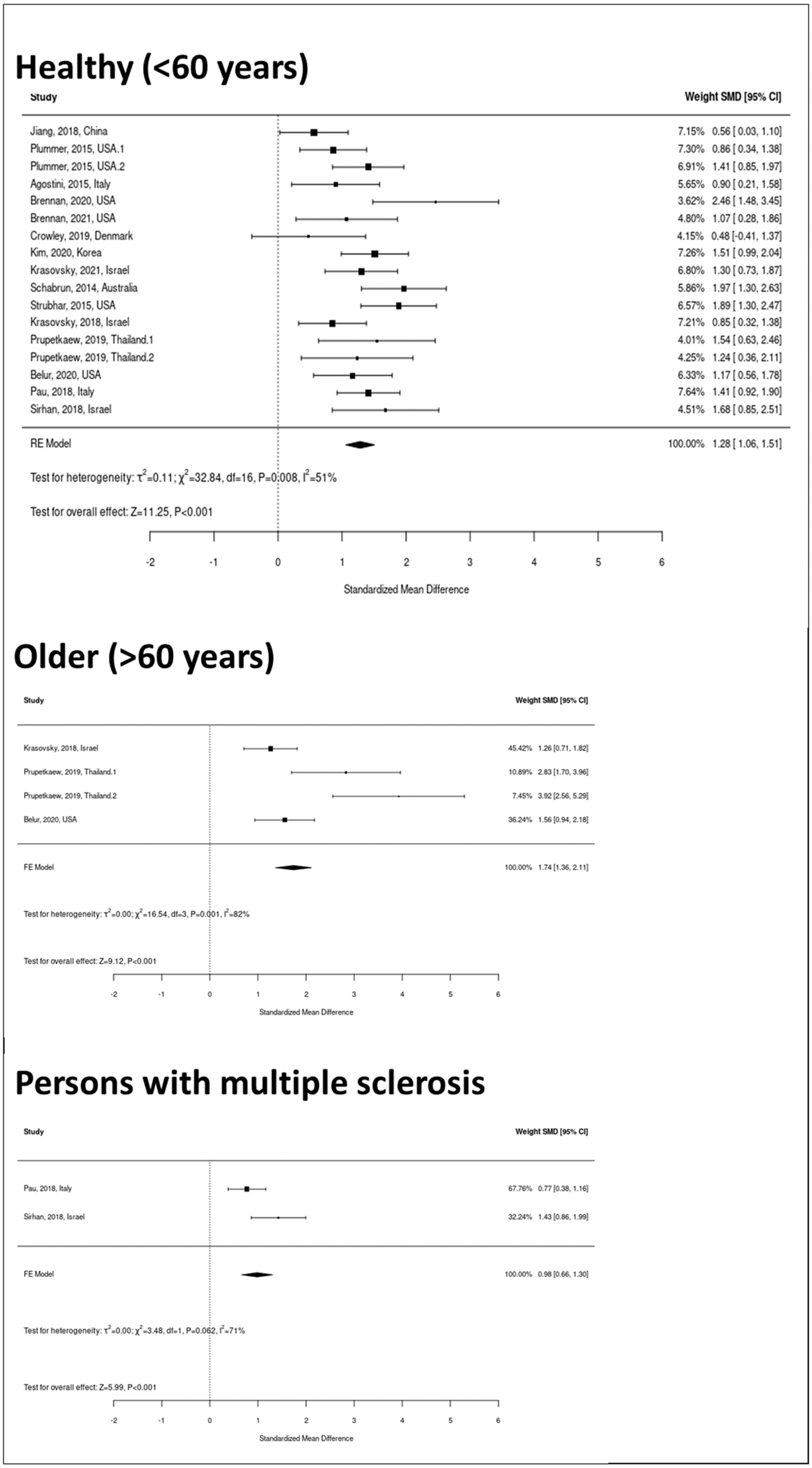

Fig. 3. Meta-analysis results for walking speed parameters for healthy adults (< 60 years), older people (≥ 60 years), and those with multiple sclerosis. RE = random-effect model. FE = fixed-effect model. SMD = standardized mean difference.

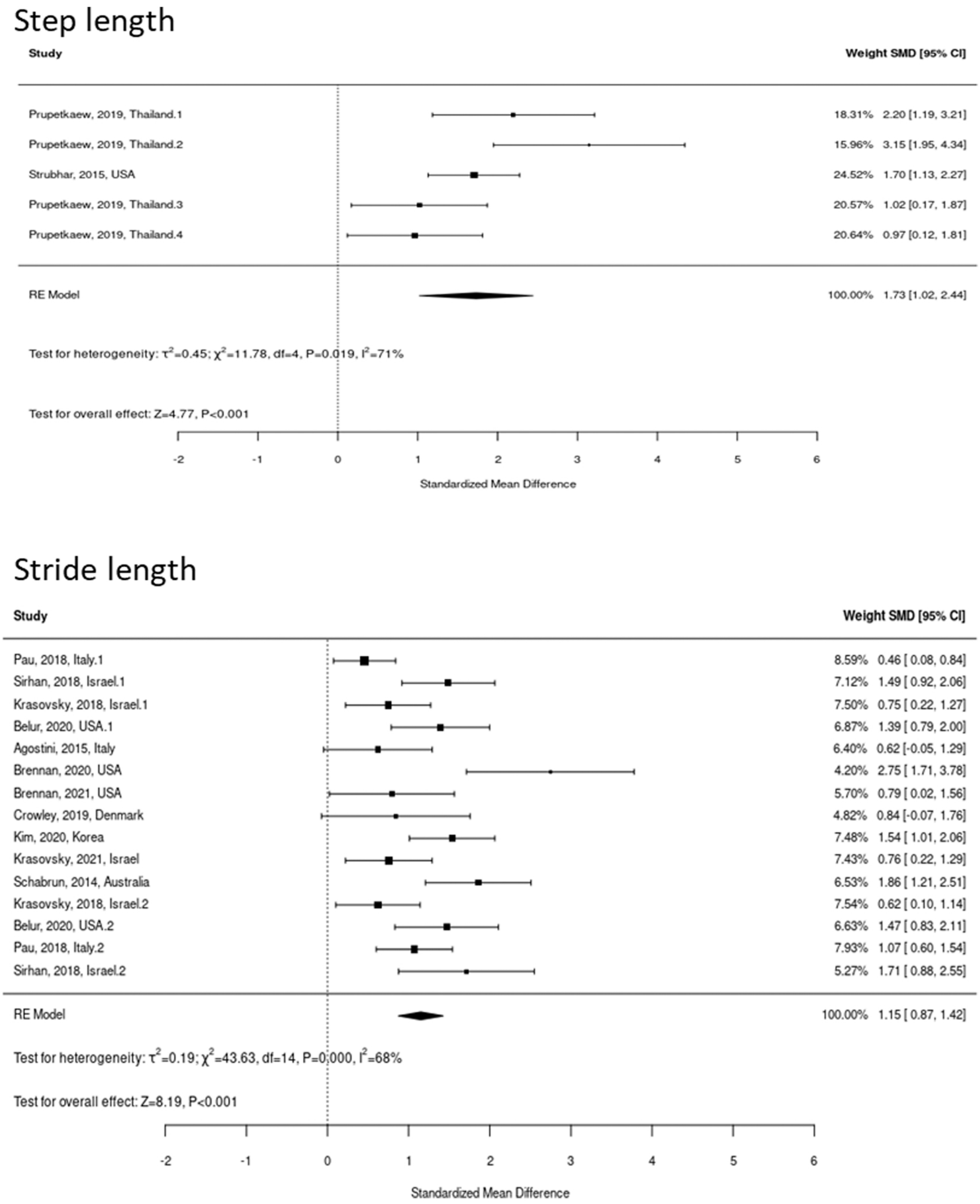

Fig. 4. Results for step and stride length parameters. RE = random-effect model. SMD = standardized mean difference.

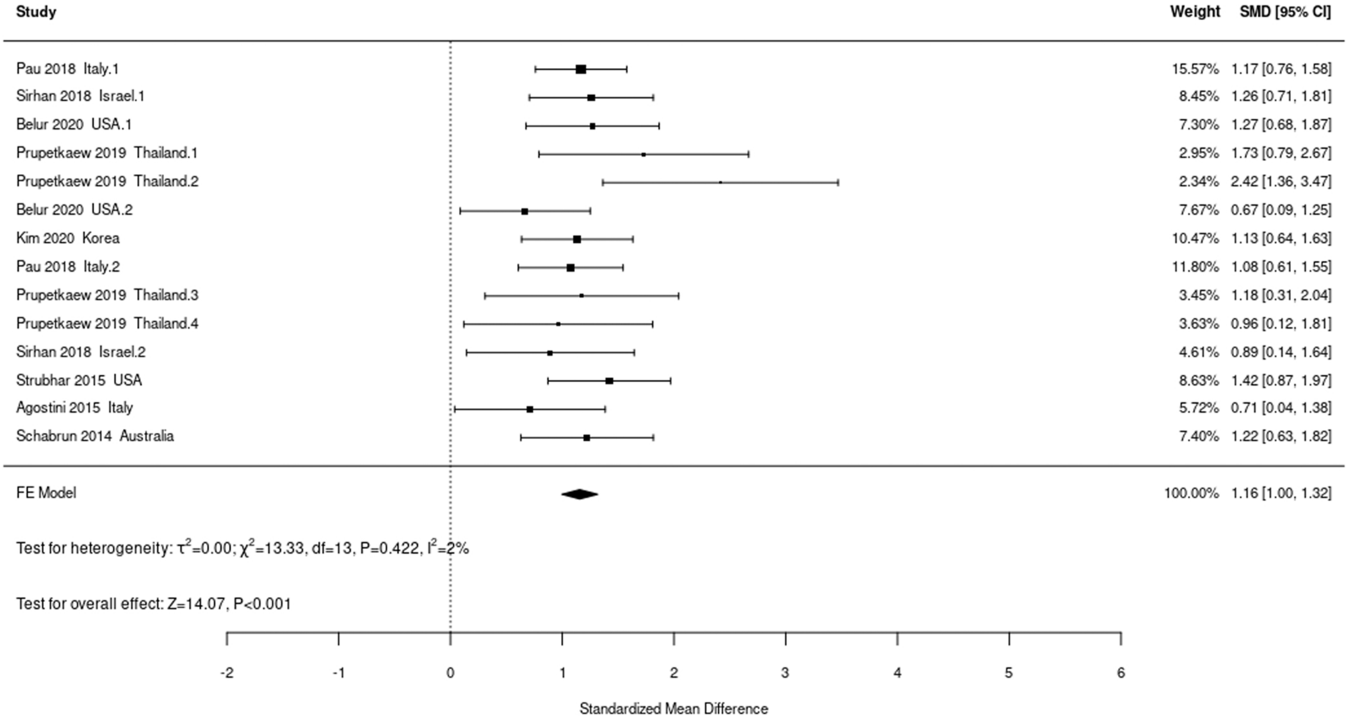

Fig. 5. Results for cadence parameters. FE = fixed-effect model. SMD = standardized mean difference.

attention. External validity was one of the commonest weaknesses in studies included in this analysis, along with power and selection bias. The population was often not representative, and the experimental conditions were far from the reality of daily life. Only three of the studies compared performances realized in laboratory vs. ecological settings [30,32,47]. All studies did not report any significant difference in walking speed between settings during the dual task "texting + walking". The heterogeneity among meta-analysis results was higher for the studies conducted in an ecological setting than in a laboratory, probably due to the quality of appraisal and the variety of the ecological conditions (e.g., campus or street crossings).

The diversity of the texting tasks in the studies may also contribute to the heterogeneity of the results. Independently evaluating each task is a characteristic of dual-tasking. However, only 16 of the 25 studies assessed texting performance (most frequently by speed, accuracy, and number of characters). Once again, the argument for exploring the effect of texting tasks is their relevance to daily life situations. However, many texting tasks reviewed in the present study were examined in controlled conditions that do not reflect the real use of the smartphone. It is noteworthy that the task proposed by Prupetkaew et al., 2019 [32]—answering questions relating to daily activities by texting—induced the slowest mean walking speed during the dual-task condition in the studies involving older adults. Overall, the lack of standardization in the texting task is a weakness when comparing the studies.

4.2. *Clinical implication*

The "distracted walking" characterized by using a smartphone when walking is the primary explanation for the increasing rates of pedestrian injuries [55]. This meta-analysis highlights a systematic disruption of the spatiotemporal parameters of gait during texting on smartphones while walking. This degradation could be attributable to a cautious walking strategy and to the postural, motor, cognitive, and visual loads of the texting task, the environment, the instructions, and the population studied. These modifications could cause a greater dynamic instability that increases the risk of accidents.

From a clinical point of view, this dual-task should be assessed frequently because it corresponds to an everyday situation for many people, including those with motor and cognitive disorders. The gait speed comparison between single task "walking" and dual-task "texting + walking", is reliable and easy to arrange in a clinical or ecological setting [20]. The performance of each task should be measured specifically. The therapist can choose to give an instruction for the prioritization of the task. Thus, it will be possible to evaluate the prioritization done (or not) by the individual. Comparing both tasks should help clinicians identify people at risk of accidents and falls [58]. Thus, advice can be given to limit this risky behavior. However, people often recognize the dangers of distracted behavior (e.g., in transportation contexts) but still engage in it [64]. Hence, targeted rehabilitation situations and prevention program (based on exercises involving combinations of motor, postural, multi-sensorial, and cognitive stimulation) for older and pathological populations would probably be more efficient than advice.

4.3. *Limitations*

The systematic review and meta-analysis involved several studies with many participants. Nevertheless, the number of studies is low for older people and individuals with pathological conditions, which limits the external validity of the results.

This review also has a language bias since only studies written in English were included. In addition, two authors were contacted for missing values but did not respond to the requests. Hence, their studies were not included in the meta-analysis.

Finally, the included studies' cross-sectional design makes it difficult to assess the appraisal quality. Following Smith et al., 2017 [26], the Downs and Black checklist was judged the most appropriate scale for this study. However, this tool is less precise than the scales used in interventional studies. For the meta-analysis, it was anticipated that the heterogeneity would be high regarding results from other reviews. To conduct the meta-analysis, the studies were filtered based on their appraisal quality. No defined cutoff for the Downs and Black scale was found; therefore, a cutoff at 9/16 was applied. Focusing on articles with a score equal to or higher than 9/16 improves homogeneity, but only moderately. Thus, the heterogeneity can be explained by the methodological quality or the diversity of the study methods.

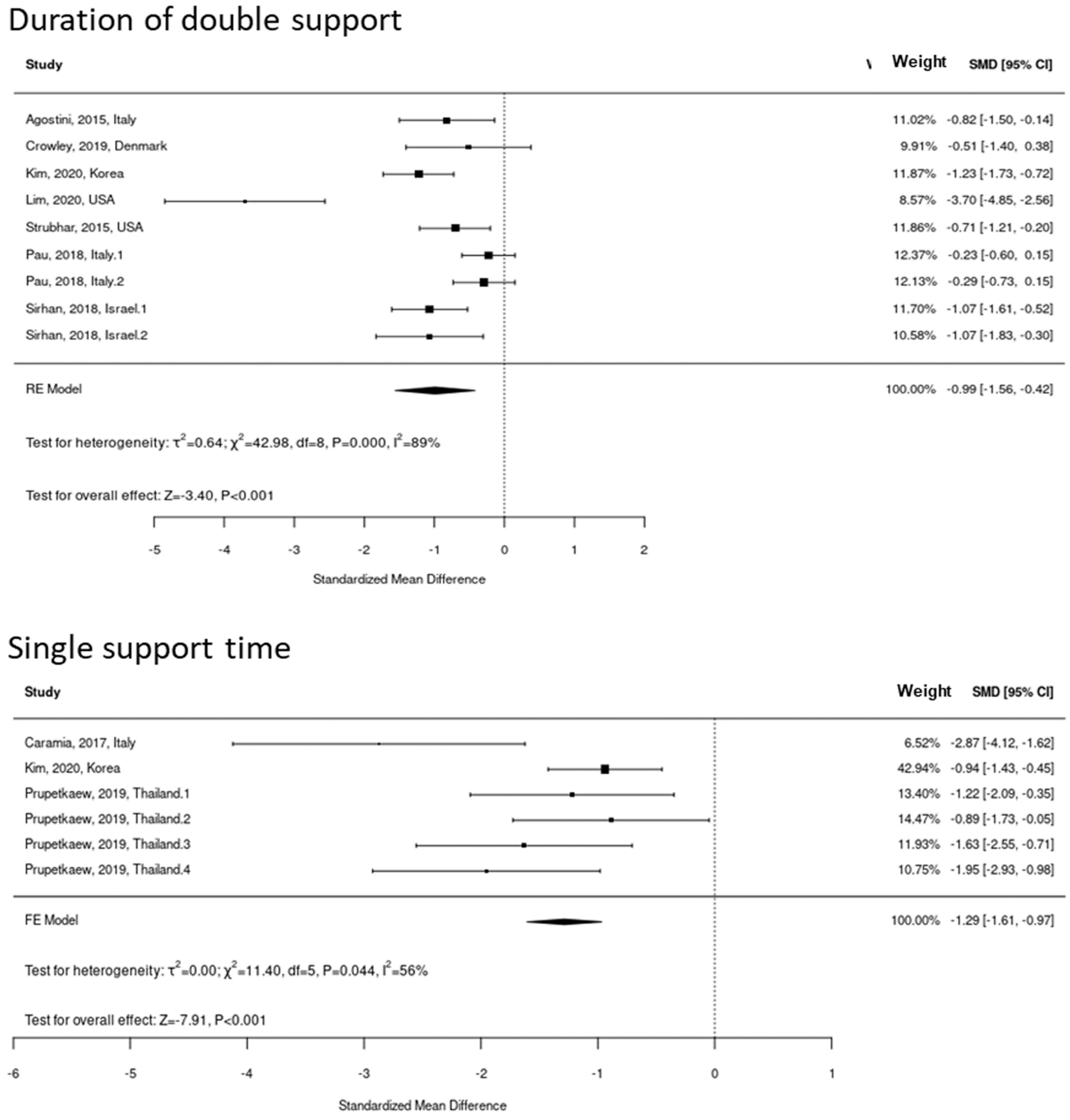

Fig. 6. Results for the duration of double support. RE = random-effect model. SMD = standardized mean difference.

5. Conclusion

Considering spatiotemporal gait parameters allows a better understanding of adaptive strategies (reduction of walking speed and step length, increase of double support duration) for managing the postural instability induced by using a smartphone while texting. Studies of the impact of texting during walking are justified by the dangers involved in performing these activities in the daily life. However, their ecological validity (predictive value of behavior in everyday life) must be checked and improved for future research since their external validity is a weakness. Studying the impact of the dual-task of texting while walking may be valuable for clinicians, especially in the context of populations at risk of falls, but standardization efforts are necessary. Other studies on vulnerable populations are also necessary and should be of high quality.

Funding

The study will be funded by the Health Research and Impulse Fund of the HES-SO, Switzerland (internal HES-SO fund with an editorial board - FRI grant 110246/S-INT21-07).

CRediT authorship contribution statement

AVB: Conceptualization, Funding acquisition, Methodology, Formal analysis, Supervision, Project administration, Examiner, Data treatment, Writing – original draft, Writing – review & editing. **AR**: Examiner, Writing – original draft, Writing – review & editing, Final approval of the version to be submitted. **SG**: Conceptualization, Registration, Final approval of the version to be submitted. **JDS**: Conceptualization, Search process in databases. **ND**: Conceptualization, Examiner, Writing – original draft, Writing – review & editing, Final approval of the version to be submitted.

Declarations of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2023.01.009.

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