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Specific smartphone usage and cognitive performance affect gait characteristics during free-living and treadmill walking

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ABSTRACT

Background: Mobile phone tasks like texting, typing, and dialling during walking are known to impact gait characteristics. Beyond that, the effects of performing smartphone-typical actions like researching and taking self-portraits (selfie) on gait have not been investigated yet.

Research question: We aimed to investigate the effects of smartphone usage on relevant gait characteristics and to reveal potential association of basic cognitive and walking plus smartphone dual-task abilities.

Methods: Our cross-sectional, cross-over study on physically active, healthy participants was performed on two days, interrupted by a 24-h washout in between. Assessments were: 1) Cognitive testing battery consisting of the trail making test (TMT A and B) and the Stroop test 2) Treadmill walking under five smartphone usage conditions: no use (control condition), reading, dialling, internet searching and taking a selfie in randomized order. Kinematic and kinetic gait characteristics were assessed to estimate conditions influence.

Results: In our sample of 36 adults (24.6 ± 1 years, 23 female, 13 male), ANCOVAs followed by post-hoc *t*-tests revealed that smartphone usage impaired all tested gait characteristics: gait speed (decrease, all conditions): $F = 54.7$, $p < 0.001$; cadence (increase, all): $F = 38.3$, $p < 0.001$; double stride length (decrease, all): $F = 33.8$, $p < 0.001$; foot external rotation (increase during dialling, researching, selfie): $F = 16.7$, $p < 0.001$; stride length variability (increase): $F = 11.7$, $p < 0.001$; step width variability (increase): $F = 5.3$, $p < 0.001$; step width (Friedmann test and Wilcoxon Bonferroni-Holm-corrected post-hoc analyses, increase): $Z = -2.3$ to -2.9; $p < 0.05$); plantar pressure proportion (increase during reading and researching) ($Z = -2.9$; $p < 0.01$). The ability to keep usual gait quality during smartphone usage was systematically associated with the TMT B time regarding cadence and double stride length for reading ($r = -0.37$), dialling ($r = -0.35$) and taking a selfie ($r = -0.34$).

Significance: Smartphone usage substantially impacts walking characteristics in most situations. Changes of gait patterns indicate higher cognitive loads and lower awareness.

1. Introduction

With over two billion worldwide users [1], smartphones and their impact on our everyday live are of increasing cultural relevance [2]. A recently published survey revealed that over 20% of the young adults use their smartphone during walking [3]. As both, smartphone usage and walking, require cognitive attention, dual-task interference caused by mobile phone handling is associated with cognitive loads and reduced situational awareness [4]. As a result, texting messages and dialling are known to impact gait characteristics [2,5] due to cognitive distraction, visual field alterations and changes in mechanical demands [4]. All these impairments may result in falls or other safety issues, such as accidents of pedestrians avoiding obstacles or crossing the road.

As stated above, most studies on this topic focused on texting and dialling situations only. Texting and dialling are suggested to increase absolute lateral foot position from one stride to another and to decrease gait speed [4], found in overground walking. Further, stride length and step cadence are different during texting and dialling than during standard walking. As reading a message, internet researching and taking a picture of oneself (selfie) may differ from the classical mobile phone tasks texting and dialling, in physical (position of the smartphone and the head), visual (eye position and/or movements), and cognitive demands, their impact on gait characteristics are of relevance but unknown yet.

Beyond standard spatiotemporal characteristics, first hints indicate that gait variability may increase when dialling on a smartphone [6].

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Table 1
Participants' anthropometrics and demographics as well as relevant co-variates (parts A and B) and neuropsychological tests (part C). n = number; MA = Master degree; BA = Bachelor degree; FoF = fear of falling; TMT = trail making test.

A	mean	standard deviation	minimum	maximum
age [years]	24.7	1.97	21.0	30.0
BMI [kg/m^2]	22.5	2.43	18.8	29.7
smartphone usage [h/day]	3.4	1.5	1.0	7
alertness day 1 [cm]	6.0	1.9	2.5	10
alertness day 2 [cm]	5.8	2.0	2.1	10
coffee consumption [cups]	2	1	0	6

B	number			
		yes	**partially**	**no**
sex	female = 23; male = 13			
drug/medication consumption [n]		0		36
educational degree	MA = 5; BA = 29; A-level = 2			
contact/collision sports		26		10
injury history lower extremity		23		13
		often	**sometimes**	**never**
phone texting/reading during walking [n]		14	21	1
phone calling during walking [n]		16	19	1
internet research during walking [n]		16	8	12
selfie during walking [n]		4	0	32
FoF during walking [n]	none = 35, some = 1, quite = 0, a lot = 0			
FoF during texting/reading [n]	none = 33, some = 3, quite = 0, a lot = 0			
FoF during calling [n]	none = 52, some = 1, quite = 0, a lot = 0			
FoF during selfie [n]	none = 30, some = 4, quite = 2, a lot = 0			
FoF during researching [n]	none = 28, some = 7, quite = 1, a lot = 0			

C	mean	standard deviation	minimum	maximum
TMT A [sec]	21.0	5.6	14	39
TMT B [sec]	44.4	11.6	21	73
Stroop colour [sec]	42.7	6.4	32	61
Stroop word [sec]	27.4	3.3	20	35
Stroop interference [sec]	66.5	11.8	46	104

Variability during repetitive movements reflects an inherent functional feature of the neuromuscular system [7]. It has recently been delineated to be of relevance for new motion patterns' learning processes [8, 9] and thus it is of relevance when rating gait characteristics under smartphone dual-task conditions.

The ability to simultaneously walk and use a smartphone might further be mediated by cognitive functions such as attention, working memory, secondarily task-switching abilities, parallel processing of the irrelevant and the relevant information and executive control. First hints indicate an association of cognitive performance and dual-task walking conditions in healthy [10]. Participants with poorer performance in working memory, secondarily task-switching abilities showed higher dual-task costs during walking. Currently no study has investigated, if such classic cognitive abilities are related to the ability of maintaining adequate walking patterns during smartphone usage as the second task.

We aimed to 1. Investigate the effects of smartphone usage (no use, calling, reading a message, internet searching and taking a selfie) on relevant gait characteristics and 2. Reveal potential association of basic cognitive and walking plus smartphone dual-task abilities. We hypothesized that smartphone usage will lead to impairments in spatio-temporal kinetic and kinematic outcomes and that these impairments are negatively associated with basic cognitive abilities.

2. Methods

2.1. Design, ethical standards and participants flow

The study adopted a cross-sectional crossover design in young, healthy and physically active individuals.

Ethical approval was obtained from the local institutional review board and the trial was conducted in accordance to the ethical standards set by the declaration of Helsinki (WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects) with its recent modification of 2013 (Fortalezza).

Participants were considered eligible if they fulfilled the following inclusion criteria: male or female aged 18–30, physically active (self-reported, > 150 min/week of physical activity), possession and regular use of a web-enabled smartphone (in everyday situations).

Exclusion criteria consisted of delayed onset muscle soreness, surgery in the previous 12 months, pregnancy or nursing period, intake of analgesics and/or perception changing substances, severe cardiovascular/pulmonary/renal dysfunction, confirmed neurologic/psychological diseases, degenerative musculoskeletal, incompletely cured injuries and alcohol consumption 12 h prior to study inclusion.

Participants were recruited by personal request of one of the authors. Interested persons were scheduled for a visit and then screened for eligibility. All participants subscribed informed consent prior to study enrolment.

2.2. Study flow

The cross-sectional, crossover study was performed on two consecutive days, interrupted by a 24-h washout period in-between. At day one, sociodemographic characteristics as well as all potential known and suggested confounders (including potential circadian rhythm confounders) and co-variates were assessed using structured interviews, followed by the cognitive testing battery, consisting of the trail making test part A and B (TMT A, TMT B) and the Stroop test. Subsequently, preferred walking speed – to be reproduced in the actual experiment

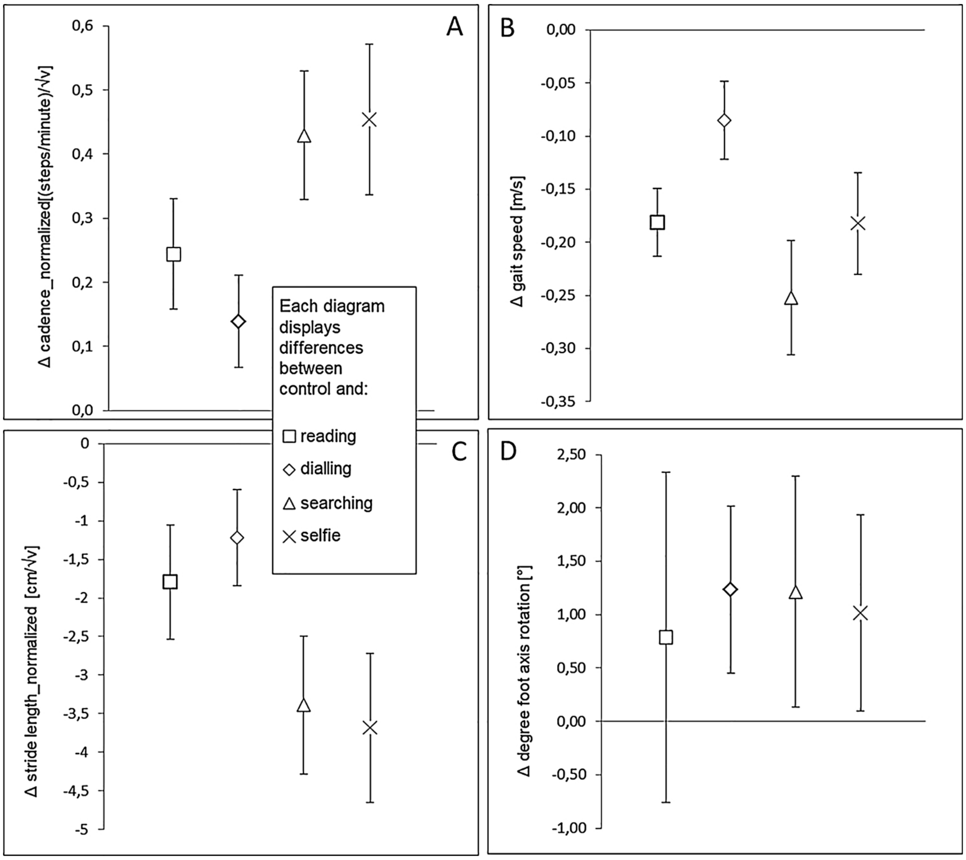


Fig. 1. Post-hoc analyses of gait characteristics including (in case of significant baseline influence) z-transformed 95%-confidence intervals of the differences between control walking and each smartphone condition. A = Normalized cadence; B = gait speed; C = normalized double stride length; D = foot axis rotation (positive values display a change into external rotation). Confidence interval not including the zero-value of the axis of ordinate indicates significant differences.

(day two) – was assessed under free-walking conditions. After the warming-up by stair stepping (step-ups on a 15 cm step, 2 min, self-selected cadence), the participants were instructed to walk a dry 50 m [11] walkway at self-selected, comfortable (preferred walking) speed under five different conditions: (1) Smartphone in trouser pocket (control condition) – (2) Reading – (3) Dialling/talking – (4) Internet searching – (5) Taking a selfie using the smartphone. Each condition was performed twice in a randomized order. The smartphone was held with one hand on the preferred side hand. The hand was the same for all trials. Each time, participants started to walk 5 m ahead the 50 m walkway starting line and maintained their walking speed for another 5 m of walk-out distance following the 50 m walkway [11]. The time [s] to pass the walkway was assessed using a handheld stopwatch, the gait speed calculated from this time. For each condition, the mean walking speed from the two trials was calculated. Thus, at day one, only gait speed was assessed for the smartphone-related outcome analysis. During this task, comfortable clothes and sporty every day shoes were worn.

On the same day, the free walking smartphone conditions were followed by the treadmill (h/p/cosmos quasar, 170 cm × 65 cm walking surface, h/p/cosmos, Nussdorf, Germany) familiarization trial. For that purpose, all participants learned to walk on the treadmill using the mean gait speed measured during the over-ground walking for each of the different conditions. Familiarization trial duration was one minute per condition.

Day two started with an initial assessment of potential circadian rhythm confounders, again. After the warming-up procedure analogue to day one, the five smartphone usage conditions during walking were performed in a randomized order and on the above described treadmill. All five conditions were standardized, assessed in 30 s periods [4] twice and in a randomized order. Thus, gait characteristics were assessed 5 × 2 × 30 s. Each condition took 40 s to assure that at least 30 s were spent performing the condition wanted. During the mean 30 s of each condition, gait data was collected.

For the dialling part, one of the investigators called the participant from another room. After the participant answered the call, common knowledge geographic questions had to be answered. Participants were instructed to immediately pick up after ringing onset. For the reading part, a standardized text (German constitution) had to be read out audible by the participant. The internet searching part included tasks on investigation on simple geographic facts, likewise. The selfie condition consisted of taking pictures of the participants own face at different facial expressions only involving the mouth in a standardized order. Smartphone had to be held at height of head with slightly flexed elbow.

All investigators were thoroughly trained and all investigations were carried out under constant conditions (same daytime (maximal ± 1 h), 24 h washout period).

2.3. Outcome assessment and data processing

The confounder and co-variates assessment contained an interview (partially self-administered questionnaire) on smartphone usage [h/day], subjective perceived cognitive alertness on a VAS-scale [cm, 0–10], coffee consumption [cups/day], drug intake/medication [n], educational degree, exposure in contact/collision sports, lower extremity injury history, habitus of handling the smartphone during texting/reading, dialling, internet research and selfie during walking as well as fear of falling during the same conditions on the treadmill.

Regarding cognitive capacity, two tests were conducted at day one. Both tests were performed seated. Within the trail making test (TMT), the first part (TMT A) assesses visuoperceptual abilities, while the TMT B covers working memory and secondarily task-switching abilities [12]. Both were done paper-pencil based. In part A, numbers from 1 to 25 have to be linked using a pencil, for part 2, the number sequence is interrupted each time by the corresponding letter (1–13; A to L) [12].

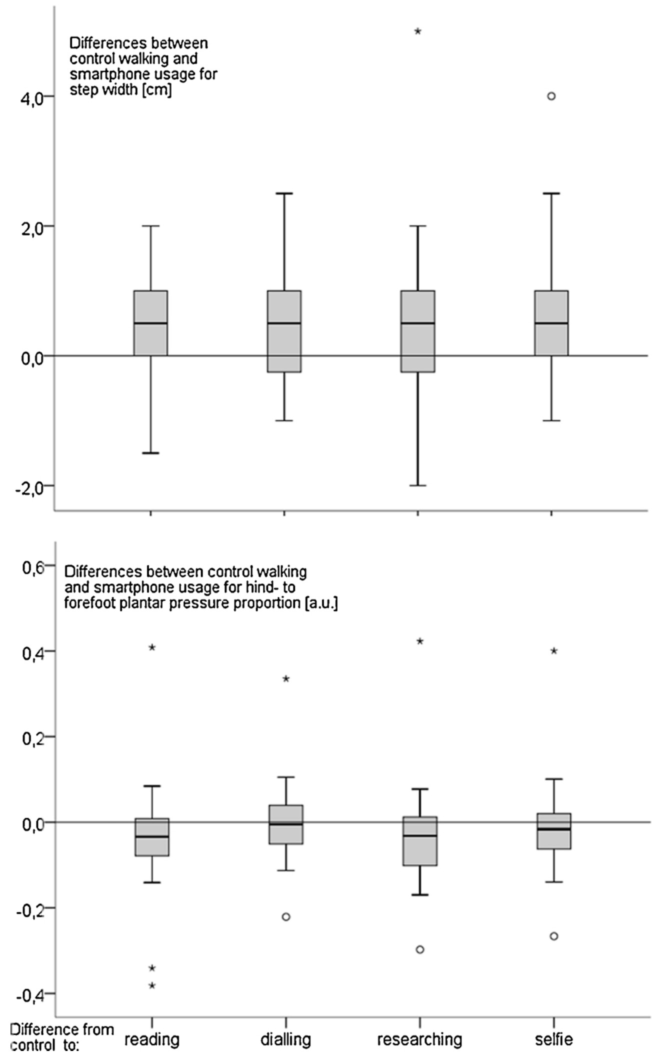


Fig. 2. Differences between control walking condition and each smartphone condition. Individual data are shown as boxplots. Each plot displays median, percentile 50 and range of data (whisker bars) incl. outliers (* and °). A decrease in hind-to forefoot plantar pressure displays an increase in forefoot and/or a decrease in hind foot pressure. A.u. = arbitrary unit.

The Stroop interference pictures parallel processing of the irrelevant and the relevant information: participants need to identify the colour a word is printed in; the word is printed in a colour that is not denoted by the word itself (for example: the word "blue" is printed in green instead of blue) [13]. The Stroop test was performed paper based. The outcome for all cognitive tests was the time [sec.] until completion. Time was assessed using a handheld stopwatch.

Gait characteristics (day two) were assessed using a capacitive force measurement platform, which is an integral part of the treadmill used (zebris FDM-T, Zebris medical GmbH, Isny, Germany). Data was collected with a sampling rate of 50 Hz. The manufacturer's software (zebris FDM Software Version 1.16.x, Zebris Medical GmbH, Isny, Germany) was used to process the following parameters: Gait speed [m/s], cadence [steps/min], double stride length [cm], step width [cm], foot external/internal rotation [°], hind-and forefoot plantar pressure [N/cm2], stance and stride times, swing phases, as well as single and double limb support durations. Foot-ground contact was calculated as the (plantar) pressure between the foot and the surface of the platform within the treadmill. Time course of this foot-ground-interaction was used for gait parameters calculation [14]. Stance and stride times, swing phases, single and double support durations were expressed in percentage of the total gait cycle. From the individualized stride length and step width, variability coefficients were calculated as CV = coefficient of variability = mean/SD. For further analyses, gait-speed-dependent outcomes such as cadence and double stride length were normalized using the individualized gait speed as they have been shown to exhibit a √v-dependency [15]. Thus, the values were divided by √v. For interpretational purposes 1. Values below 1 for foot pressure proportion indicate higher forefoot pressure, 2. Negative values for foot rotation show internal and positive values show external rotation.

Gait outcome measures during smartphone usage (i.e. texting) have recently been shown to be of good to excellent reliability [16].

2.4. Statistical analyses

Following plausibility control the statistical analysis was performed based on the results of checking the data for underlying assumptions for parametric or rather nonparametric testing. All statistical calculations were conducted using SPSS 20 (SPSS Inc., Chicago, IL, USA).

Parametric testing was performed using ANCOVAs (potential confounders as Co-Variates) to test for differences between conditions for gait speed (velocity), cadence, stride length, and foot rotation, as well as for the variability of double stride length and step width. In case of significance, post-hoc z-transformed (in case of a significant impact of the baseline-values) 95%-confidence intervals were calculated for differences between control walking and each smartphone condition. Nonparametric analyses included Friedman-Omnibustest and – in case of significance – Wilcoxon-alpha-error adjusted post-hoc testing for differences between control walking and each smartphone condition for step width and plantar pressure proportion. All confirmatory tests were done incl. post-hoc-alpha error adjustment according to Bonferroni-Holm for group x time differences. A 5% error probability was

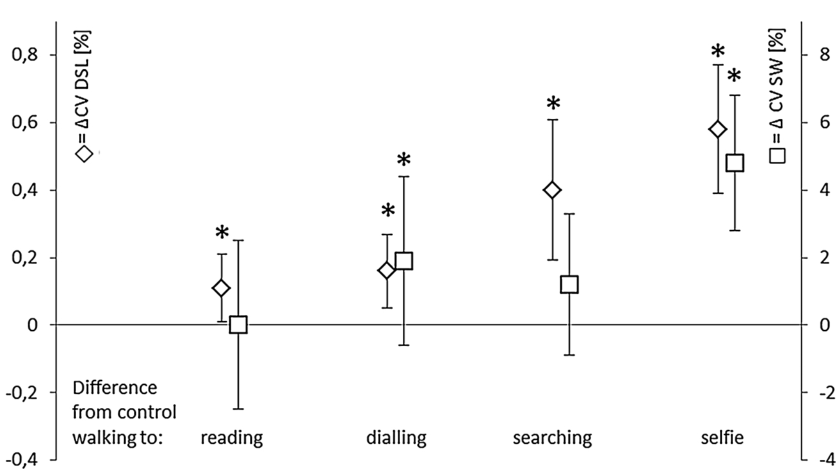
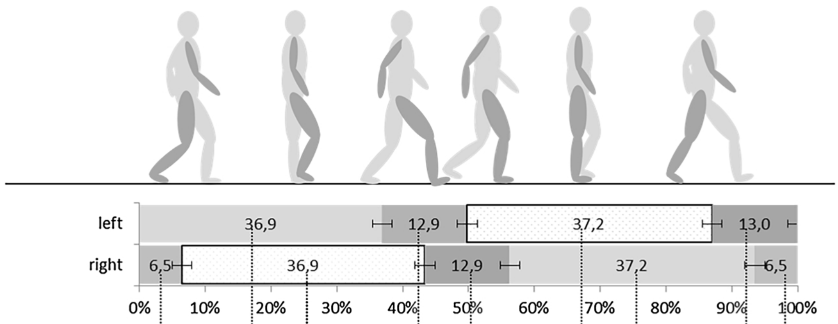


Fig. 3. Post-hoc analyses including (in case of significant baseline influence) z-transformed 95%-confidence intervals of the differences between control walking and each smartphone condition for CV double stride length and CV step width. DSL = double stride length; SW = step width; * = significant under the level of at least 5%.



% mean difference from free walking to	Pre-swing (R)	Midstance (L)	Swing (R)	Pre-swing (L)	Loading response (R)	Swing (L)	Midstance (R)	Loading response (L)	Pre-swing (R)
reading	0,55	-1	-1,1	1	1	-1	-1	1	0,55
calling	0,3	-0,5	-0,6	0,6	0,5	-0,5	-0,6	0,5	0,3
searching	0,75	-1,5	-1,5	1,5	1,5	-1,5	-1,5	1,5	0,75
selfie	0,5	-1	-1	1	1	-1	-1	1	0,5

Fig. 4. Gait cycle (homunculus) with its different components (bars). Percentage proportions and standard deviations are shown for control walking. All data is displayed for control walking and the differences between control walking and each smartphone condition (table). R = right, l = left.

Table 2
Explorative associations of cognitive outcome results with the differences from control to smartphone conditions in double stride length (DSL) and cadence. * = p < 0.5. SD = standard deviation.

	Δ DSL to reading [cm/√v]	Δ DSL to calling [cm/√v]	Δ DSL to researching [cm/√v]	Δ DSL to selfie [cm/√v]	Δ Cadence to reading [s^{-1}/√v]	Δ Cadence to calling [s^{-1}/√v]	Δ Cadence to researching [s^{-1}/√v]	Δ Cadence to selfie [s^{-1}/√v]
TMT A [sec] Mean 20.9 SD 5.6	0.06	−0.08	−0.08	−0.05	0.08	−0.02	0.1	0.08
TMT B [sec] Mean 44.4 SD 11.5	−0.36 *	−0.34 *	−0.2	−0.4 *	0.32 *	0.22 *	0.18	0.33 *
Stroop interference [sec] Mean 66.5 SD 11.8	0.02	−0.17	0.02	0.08	−0.01	0.2	0.01	−0.05

tolerated.

Cognitive outcomes were analysed for their value in variance explanation on the changes in gait characteristics between control walking and each smartphone condition; again in dependence of the underlying assumptions using Spearman or Pearson analysis.

3. Results

No participant revoked informed consent or had to be excluded after study enrolment. Table 1 shows the anthropometric and demographic data as well as the relevant potential confounding variables and covariates (cognitive and functional values) and the cognitive outcomes (TMT A and B, Stroop-Test).

The ANCOVAs for gait speed (velocity), cadence, stride length and foot rotation for differences between conditions revealed systematic differences between the control condition (no phone) and the smartphone usage conditions: gait speed (velocity): $F = 54.7$, $p < 0.001$; cadence: $F = 38.3$, $p < 0.001$; double stride length: $F = 33.8$, $p < 0.001$; and foot rotation: $F = 16.7$, $p < 0.001$. Included co-variates (except control walking values) did not impact the model ($F < 2.1$; $p > 0.05$). Bonferroni-Holm-corrected post-hoc analyses including (in case of significant baseline influence) z-transformed 95%-confidence intervals of the differences between control walking and each smartphone condition are shown in Fig. 1. Control condition values were as follows: gait speed (velocity) – mean 1.48 m/s SD 0.15 m/s range 1.14 m/s–1.67 m/s; cadence – [(steps/min)/√(m/min)]: mean 12.8 SD 0.52 range 11.7–13.7; double stride length [cm/√(m/s)] – mean 121 SD 4.8 range 113–132; and foot rotation – mean 9.9° SD 7.8° range −3.8°–29.4°.

The Friedman-testing for step width [cm] and plantar pressure hind-to-forefoot proportion for differences between conditions revealed systematic differences between control walking and the mobile usage conditions: step with: $Chi^2 = 9.8$, $p < .05$; and plantar pressure proportion: $Chi^2 = 11.8$, $p < 0.01$. The differences between walking and each smartphone condition are shown in Fig. 2. Wilcoxon Bonferroni-Holm-corrected post-hoc analyses of these differences revealed significant differences between control walking and all smartphone conditions for step width ($Z = -2.3$ to -2.9; $p < .05$) but only between control and reading ($Z = -2.5$; $p < 0.05$) and between control walking and researching ($Z = -2.9$; $p < 0.01$) for plantar pressure proportion. Baseline control values were as follows: step width – mean 8.8 cm SD 2 cm range 5.5–13 cm; foot pressure proportion – mean 1.0 a.u. SD 0.26 a.u. range 0.68–1.69 a.u.

The ANCOVAs for the variability of double stride length and step width revealed systematic differences between control walking and the mobile usage conditions: Coefficient of variation (CV) of stride length: $F = 11.7$, $p < 0.001$; CV step width: $F = 5.3$, $p < 0.001$. Bonferroni-Holm-corrected post-hoc analyses including (in case of significant baseline influence) z-transformed 95%-confidence intervals of the differences between control and each smartphone condition are shown in Fig. 3. Control walking values were as follows: CV stride length – mean 1.1% SD 0.29% range 0.6%–1.6%; step width – mean 24% SD 8% range 9.5%–50%.

Fig. 4 displays the gait cycle. The different phases for smartphone-free walking and the differences between control condition and each smartphone condition are displayed. Each gait cycle part differed significantly from control walking ($p < 0.01$). Double stance phase increased from (control) mean 25.9% SD 2.9% to 27.3 ± 2.9 (reading), 27.1 ± 2.8% (dialling), 28.8 ± 3.0% (researching) and 27.9 ± 2.9% (selfie) ($p < 0.01$).

Explorative correlation analyses (Spearman bivariate) revealed slight associations between TMT B and differences in cadence and double stride length, but not for all the other tests (Table 2).

4. Discussion

Dialling, reading a message, internet searching and taking a selfie with a smartphone affect the way we walk. Gait speed, cadence, double stride length, foot external rotation, stride length, variability measures, step with and plantar pressure proportion were all different under smartphone dual-task conditions as compared to control condition. Consequently, the data collected in the present study corroborate our assumed hypotheses.

With a mean duration of 33.8 s for the 50 m walkway, our participants' habitual walking speed was comparable to a group of young healthy participants in a previous study (mean 35.3 s for the 50 m) [11]. In the same study, a speed reduction of up to 1.2–1.3 m/s was found upon smartphone usage. These values are, again, in accordance with ours (1.22 m/s–1.39 m/s depending on the different conditions). Our sample and measures are thus considered representative.

Recent research, inter alia, has elaborated that writing text messages or dialling with a cell phone impacts gait characteristics negatively in comparison to normal walking [2,5]. More precise, texting and dialling are responsible for a decreased gait speed [4], stride length and step cadence. Stride length and step cadence often directly result from gait speed reduction; keeping gait speed constant to subtract this association would have been misleading since the gait characteristics would not be assessed under real conditions [17]. Normalization on the self-selected gait speed using a $\sqrt{v}$-association [15], as we have done it in this study, can thus be considered more appropriate for gait-speed-dependent outcomes. A study examining this association suggest such a normalisation for stride length, cadence and gait cycle parameters but not for step width or kinetic parameters [15].

From this point of view, cadence increases and double stride length decreases during all smartphone dual-task conditions investigated in our sample. As, additionally, most studies on smartphone usage during walking focus on texting and dialling only, our study expands actual knowledge by adding smartphone-typical conditions like internet searching and taking a selfie. Taking all conditions into account, a specific and characteristic pattern can be found: Researching and taking a selfie have a larger impact on gait than reading or dialling. Speculatively, researching likely employs physical and visual demands which are comparable to reading or texting whereas taking a selfie seems to be more challenging on the physical demand as the arms are raised and forwarded. This pattern is not only typical for standard gait characteristics, but also for the percentage amounts of single, double limb support, and swing phases of the complete gait cycle. Nevertheless, according to the explorative sub-analysis, these constant patterns were not associated with habitual smartphone usage during the different conditions or fear of falling but may indicate a higher impact of more complex cognitive tasks. Plantar pressure distribution represents an exception: only reading a message and researching change the pressure as follows: the forefoot pressure increases. A reason for this might be found in the smartphone handling (in front of the body) and the herewith associated change in body posture (centre of pressure moves into anterior direction). However, if the smartphone handling is the only reason for the difference in plantar pressure or not stays a matter of debate. A slightly different characteristic is, likewise, seen for foot axis rotation: while reading does not affect foot rotation, dialling, researching and taking a selfie increase external rotation of the foot during walking. In contrast to reading, which represents a passive cognitive dual task, the other conditions contain an active motor component. It might therefore be speculated that the external rotation of the feet reflects the body's strategy to increase step safety by activating the hip rotators.

Beyond classical gait characteristics, variability of repetitive steps was recently shown to be increased under various dual-task conditions [18], not least during cell phone texting and dialling when walking [6]. Here, a significant increase in stride width variability has been described. Currently, movement variability is defined as the normal variation occurring during natural motor performance [19]. Normal and, in particular, unknown or new motor skills are accompanied by an "optimal" level of variability [20]. Just as at the standard gait characteristics, a constant pattern is seen whilst reading and calling. In contrast, a profound increase (except for CV in step width for researching) of the variability was found during researching and selfie. One may speculate that these tasks consequently are cognitively more challenging.

Furthermore, the ability to use a smartphone during walking without or with only slight gait characteristics affection was systematically associated with the TMT B results. This was the case in double stride length and cadence for the conditions reading, dialling and taking a selfie only. Simple visuoperceptual abilities, as tested in the TMT A [12], are though not the determinant neurocognitive ability during everyday mobile phone usage during walking. As the TMT B reflects working memory and secondarily task-switching abilities [12], these abilities may be crucial for smartphone dual-tasking. However, the comparably low associations between working memory, secondarily task-switching and reading, dialling, taking a selfie do not allow derivations of a powerful identification of participants with an increased risk of not being able to compensate smartphone dual-tasking to a lesser extent. The results for the Stroop interference test as a picture of parallel processing of the irrelevant and the relevant information [13] were not associated with the ability to compensate smartphone usage during walking. Consequently, task-switching skills seem to be more relevant than interference competences to prevent gait characteristics decrements during smartphone utilization. Further study discusses cognitive distraction, visual field alterations and changes in mechanical demands as important factors for the impairments found during smartphone utilization [4].

A recently published trial has elegantly shown that gait measures during texting are reliable [2]. This is the first hint for sufficient accuracy of our results. With the focus on clinically important difference, the between–day repeatability of gait parameters has been shown to be similar to within–day, both displaying a minimum detectable change between 3 % and 17 % for temporal, 4 % and 20% for kinetic, and 14% and 33% for spatial outcomes [21]. The minimum detectable change as the minimum change to reflect a relevant change and not solely an error in measurement was $\Delta = 0.03$ m/s for gait speed. As the changes from control walking to all smartphone dual-task conditions were (mean and complete confidence interval) far larger than this cut-off value, our results are of clinical relevance.

However, some limitations have to be taken into account. Although we aimed to best possible standardize the testing situation, treadmill walking always differs from free walking in various conditions. A free walking route with in-ground force measurement platforms might provide conclusive information.

Our results are of practical relevance. Even small stride-to-stride alterations from normal walking may lead to an increase an individual's risk of falling [22]. The decrease in gait speed and double step length, the increase in cadence and step width as well as the changes in gait cycle percentage amounts may all display a change in gait reflecting an uncertainty of the participants. When patterns which shall increase subjective gait safety or stability are applied (and thus avoid falls), less confidence in the gait stability may be underlying. This uncertainty is caused by smartphone dual-task conditions. Together with the increased risk of stepping on an unstable surface or an obstacle with the increased step width [23,4], the uncertainty patterns in gait characteristics during smartphone use may put the participants at a greater risk for falls and injury. Further, one may speculate that the increase in foot external rotation leads to a change in musculoskeletal stress; this issue itself may lead to dysfunctional or even pathological loads.

Finally, a decrease in gait speed is associated with a lower health benefit of the walking, even after adjustment for several potential confounders, slower daily living walking speed is associated with an increased risk of cardiovascular mortality [24], running smartphone usage thus be of cardiovascular and not only musculoskeletal threat. Although no one would use the smartphone while walking as a main exercise to increase their health benefit, the benefit of walking in daily living situations beyond exercising may be affected.

Consequently and supported by our data, policy decision makers and civil societies are in charge to promote knowledge on the potential negative impact of smartphone usage while walking [3,25].

5. Conclusion

Smartphone usage substantially impacts gait characteristics. The increase in step width and double stance time together with the decrease in stride length displays a compensation of uncertain gait. It displays higher cognitive loads and lower awareness, potentially leading to higher risk for falls and injury risks.

Conflict of interest statement

None declared.

Acknowledgement

None.

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