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Texting while walking: An expensive switch cost

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ABSTRACT

Texting while walking has been highlighted as a dangerous behavior that leads to impaired judgment and accidents. This impairment could be due to task switching which involves activation of the present task and the inhibition of the previous task. However, the relative contributions of these processes and their brain activity have not yet been studied. We addressed this gap by asking participants to discriminate the orientation of an oncoming human shape in a virtual environment while they were: i) walking on a treadmill, or ii) texting while walking on a treadmill. Participants' performance (i.e., correctly identifying if a walker would pass them to their left or right) and electroencephalography (EEG) data was collected. Unsurprisingly, we found that participants performed better while they were only walking than when texting while walking. However, we also found that the diminished performance is differently related to task set inhibition and task set activation in the two conditions. The alpha oscillations, which can be used as an index of task inhibition, have a significantly different relation to performance in the two conditions, the relation being negative when subjects are texting. This may indicate that the more inhibition is needed, the more the performance is affected by texting. To our knowledge, this is the first study to investigate the brain signature of task switching in texting while walking. This finding is the first step in identifying the source of impaired judgment in texting pedestrians and in finding viable solutions to reduce the risks.

1. Introduction

The use of smartphones is rapidly growing around the world. In the United States, its penetration rate reached 81% in 2016 (Lella, 2017). The negative impact of mobile phone use on drivers' safety has been widely demonstrated (Svenson and Patten, 2005; Horrey and Wickens, 2006; Drews et al., 2009; Owens et al., 2011). However, the safety hazards related to mobile phone use do not only apply to drivers. Although total pedestrian injuries have decreased from 2005 to 2010, mobile phone-related injuries involving pedestrians have increased and, in 2010, exceeded those of drivers for the first time since 2005 (Nasar and Troyer, 2013). These injuries occurred most often among men and among people under 31 years old (Nasar and Troyer, 2013). Jehle (2014) suggests that "When texting, you're not as in control with the complex actions of walking…While talking on the phone is a distraction, texting is much more dangerous […]." Until now, studies on the impact of handheld mobile technologies on pedestrian safety have exclusively used observational and/or behavioral data. In an observation study conducted at multiple metropolitan high risk intersections, Thompson et al. (2013) found that 30% were engaged in distracting activities while crossing (e.g., listening to music (11%), texting (7%), talking (6%)). Stavrinos et al. (2011) investigated the impact of cellphone conversation on pedestrians' distraction and tendencies to display riskier behaviors. Their study revealed that cellphone conversations considerably distracted college pedestrians for most measured pedestrian safety variables (e.g., instances when participants would have been struck by a vehicle). Schwebel et al. (2012) and Byington and Schwebel (2013) used a semi-immersive virtual environment to study the impact of different multimedia devices (listening to music or texting) on pedestrian safety. They report that subjects using a multimedia device took more time to cross the street, missed several safe opportunities to cross, took longer to initiate crossing when a safe gap was available, looked left and right less often, spent more time looking away from the road, and were more likely to be hit or almost hit by an incoming vehicle. In addition, Hyman et al. (2010) found that individuals using a cellphone while walking (listening to music, talking) were less likely to acknowledge other people, changed directions more frequently, and walked more slowly. In short, based on observational

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and behavioral data, current research suggests that using a smartphone while walking causes an important threat to pedestrian safety. Research also indicates that most safety hazards stemming from using smartphones while walking are likely caused by attentional impairments (Hatfield and Murphy, 2007; Nasar et al., 2008; Hyman et al., 2010; Stavrinos et al., 2011; Pourchon et al., 2017).

In order to further understand these attentional impairments, the aim of the present study is to shed light on the underlying cognitive and attentional effects of smartphone use by pedestrians using neurophysiological data. By investigating pedestrian cognitive responses (i.e., cognitive engagement and alpha oscillations), this study extends prior observational and behavioral research by providing an in-depth explanation of the underlying cognitive phenomena at play when pedestrians use their cellphone.

The National Electronic Injury Surveillance System (NEISS) reported that from 2009 to 2013, the number of incidents involving texting while walking was twice the number of incidents involving talking while walking (Commission, 2013). Furthermore, texting may be one of the most interfering tasks for pedestrians. Schwebel et al. (2012) report more cognitive distraction and decision mistakes caused by texting compared to talking when using a cellphone. Moreover, texting is the application most frequently used by cellphone owners (eMarketer, 2017). We thus focus on texting while walking (TWW) in our study.

As most pedestrian security issues result from distraction while performing a concurrent action requiring cognitive and attentional resources (e.g., crossing the street, avoiding another pedestrian), we framed our TWW study in the multitasking literature and, more precisely, in the task switching paradigm. In typical task switching experiments, subjects perform two tasks in a sequential order (e.g., AABBAA) (Monsell et al., 2003). Each task requires attention on a particular part or feature of the stimulus. The appropriate response to the stimulus in Task A or B requires a specific configuration of mental resources defined as a "task-set" (Monsell, 1996). In most studies, when task switches are unpredictable, the stimuli are preceded by a cue indicating which task to perform. The difference in response time and/or error rate between switch trials and non-switch trials is defined as the "switch cost" (Wylie and Allport, 2000). When subjects change from Task A to Task B, the mental resources need to be reconfigured to fit the upcoming task. This process of "Task-Set Reconfiguration" (TSR) is identified as the main cause of switch cost (Rogers and Monsell, 1995a; Meiran, 1996; Monsell and Mizon, 2006). Monsell (2003) describes TSR as a "gear changing", involving the activation of the current task-set and the inhibition of the previous one. It must be achieved before task-specific processes can occur. The switch cost reflects the additional processes required to perform TSR during a change of task. By manipulating the cue-stimulus interval, research has shown that increasing the preparation time before stimulus onset can reduce switch cost as some task-set activation processes can be performed in advance (e.g., goal activation, attentional shifting) (Meiran, 1996; Monsell and Mizon, 2006). However, preparation has rather an asymptotic effect and a "residual cost" is generally present after a task switch (Allport et al., 1994; Nieuwenhuis and Monsell, 2002). According to the theory of task-set inertia, the residual cost reflects a carry-over effect of the previously active task-set (Allport et al., 1994; Yeung et al., 2006). The dissipation of the irrelevant task-set is undergone by the TSR subprocess of "task-set inhibition". As inhibition is a passive exogenous process performed only after stimulus onset, it would be impervious to preparation effects.

Based on the task-set inertia theory (Allport et al., 1994; Nieuwenhuis and Monsell, 2002) and on the literature on pedestrian attentional impairments while using a cellphone (Hatfield and Murphy, 2007; Nasar et al., 2008; Hyman et al., 2010; Stavrinos et al., 2011; Pourchon et al., 2017), we suggest that pedestrians will incur greater switch costs (i.e., greater carry-over effects) when switching their attention from texting while walking to their immediate surroundings than when switching their attention from walking to their immediate surroundings. The greater switch costs will have a negative effect on pedestrians' safety performance.

To further study the impact of smartphone use on pedestrians' task switching performance, participants in our study were engaged in multitasking episodes (i.e., texting and walking) based on an adaptation of the task switching paradigm. We investigated the different roles played by task-set inhibition and task-set activation on switch cost in the context of TWW. The experiment took place in an immersive virtual environment in which subjects had to walk on a treadmill while their EEG activity was recorded.

2. Methods

2.1. Participants

Fifty-four participants (31 females, 23 males) took part in the experiment Participants were between 18 and 49 years old (a sample average of 24). The experiment was performed over a period of one month. All participants had normal or corrected-to-normal vision and were pre-screened for glasses, epilepsy, and neurological and psychiatric diagnoses. All participants were either undergraduate or graduate students from our institution. A $50 gift certificate compensation was given upon experiment completion. This study and all its procedures were approved by the first author institution's Ethics Research Committee. All participants were at least 18 years old and provided written consent.

2.2. Apparatus

The experiment took place in a fully immersive virtual environment, the CAVE system (Fakespace™). The CAVE is an 8 × 8 × 8 feet room including three canvas walls (one frontal and two lateral) and an epoxy floor. The CAVE was installed in a light and sound-proof room. While participants walked on a treadmill, a point-light walker figure reproducing biological motion was displayed walking toward the participant with a small angle deviation. Participants were then asked to verbally identify the walker's direction (Legault et al., 2012). Biological motion (BM) refers to a movement pattern characteristic of humans and animals (Johansson, 1973). We chose a BM stimulus for two main reasons. First, it represents an ecologically valid stimulus in the context of texting while walking as pedestrians are almost always surrounded by other pedestrians. Second, the four stages of BM perception (detection of animate motion, structure from motion, action perception, and style recognition) impose a relatively important information processing level on the visual system (Troje, 2008). BM perception involves a complex hierarchy of visual information processing and requires attentional resources to be processed successfully (Cavanagh et al., 2001; Troje, 2008). Using a dual-task paradigm, Thornton et al. (2002) found that performance on point-like walker direction identification is strongly affected by divided attention. It is, therefore, a suitable task for evaluating the switch cost of texting while walking in an authentic context.

A dynamic point-light walker representation of a walking human form composed of 15 black dots was used. The dots, representing the head, shoulders, hips, elbows, wrists, knees, and ankles, were presented on a white background. The walker stimulus was constructed using the average motion-capture data of 50 males and 50 females (see Troje (2008) for more details on the stimulus generation). The walkers were displayed on the frontal wall with a resolution of 1280 × 1024 pixels, generated by a Marquee Ultra 8500 projector. Walkers were presented walking either leftward or rightward with a deviation angle of 3.5° (or −3.5°) from the participant (see Fig. 1).

Participants were walking on a regular consumer treadmill (Tempo Fitness, Wisconsin, USA) wearing running shoes (see Fig. 1). The treadmill speed in our experiment was set to 0.36 m/s. This speed was

Fig. 1. Experimental apparatus. The presented stimulus has a −3.5° orientation angle and is walking to the left of the participant.

found to be the most comfortable and safe one during pretests prior to the experiment. Participants were texting with a research assistant using the iMessage application on an iPhone 4 s (Apple, California, USA). The research assistant kept the conversation flowing using a predefined set of topics and open-ended questions. Questions and topics were conceived in such a way as to avoid strong emotional reactions (e.g., “What transportation means do you most often use?”, “What is your favorite movie?”). After a round of 4–5 questions/answers on a topic, the research assistant would move on to the next conversation topic.

2.3. Procedure

The present experimental design was adapted from the common task switching paradigm to better represent an ecologically valid TWW situation. In most task switch studies, the same stimulus is used to afford two (or more) different tasks. Each task requiring the participant to focus on a different part of the stimulus. A task switch occurs on trials in which the cue indicates a stimulus-response rule different than the preceding trial. In our experiment, the same task (orientation identification) always follows the stimulus cue. Two within-subject experimental conditions were included in the experiment. As depicted in Fig. 2, in the TWW condition, Task A consisted of texting while walking, and in the walking condition, Task A consisted in simply walking and looking forward. In both conditions, Task B was composed of the same cue, stimulus, and response sequence.

Participants were walking on the treadmill in both conditions. The auditory cue was coming from two speakers placed in front of the treadmill (see Fig. 1), indicating to the participants to raise their head and look at the projection wall. The cue-stimulus interval was set to 1 s. The walker was then displayed for the duration of 1 s, representing 2 to 3 gait-cycles. Participants had to verbally answer “left” of “right”, according to the side they perceived the walker would pass them. In accordance with a two-alternative forced choice method, the research assistant administering the experiment would require an answer if a participant had missed the stimulus. Participants would then keep walking and, in the TWW condition, continue the texting conversation until the next cue. The experiment was composed of 4 blocks: two blocks for the TWW condition (2 × 22 trials) and two blocks for walking condition (2 × 22 trials). The duration of a block was approximately 12 min. The order of the blocks was counterbalanced (half of the participants started with the TWW condition block) and the blocks were separated by a two-minute break in which participants could sit on a chair and drink water. Prior to the first block, participants had a two-minute period to get used to walking on the treadmill followed by a three-minute practice period to text with the research assistant while walking on the treadmill. The total experiment duration was 70 min for the 4 blocks. A total of 88 trials per participant were collected.

2.4. EEG recording and data analysis

Although electroencephalographic (EEG) data has been used extensively to study drivers’ cognitive activity (e.g., Wester et al., 2008; Zhao et al., 2012; Fort et al., 2013; Sonnleitner et al., 2014), EEG data recorded during on foot locomotion has, until recently, been considered too noisy to obtain conclusive results (Gwin et al., 2010); but new active electrode technology now makes it feasible. Neurophysiological measures allow for the acquisition of detailed information about the time course of the cognitive processes that take place incredibly quickly in the fraction of a second when a pedestrian has to react. Behavioral measures and other physiological data do not have the temporal precision required for thoroughly understanding what takes places in that time.

EEG activity was recorded with an actiCAP set of 32 active electrodes (Brain Products, Germany). Active electrodes combine Ag/AgCl sensors with a noise subtraction circuit to allow recording during walking. This was used with an EGI amplifier (Electrical Geodesics, Oregon, USA). The vertex (recording site Cz) was the reference electrode for recording. Impedance was kept below 50 kΩ with a sampling rate of 250 Hz. Data analysis was performed with Vision Analyzer 2 (Brain Products, Germany). The data was filtered offline with a lowpass IIR filter at 20 Hz and a highpass IIR filter at 1 Hz. An Independent Component Analysis (ICA) was applied to attenuate the movement of eye blinks and ocular saccades in the EEG data (Jung et al., 2000). An automatic artifact rejection was used to exclude epochs with voltage differences over 50 μV between two neighboring sampling points and a difference over 50 μV in a 75 ms interval. Data was re-referenced to the common average reference, that is, the average of all the electrodes

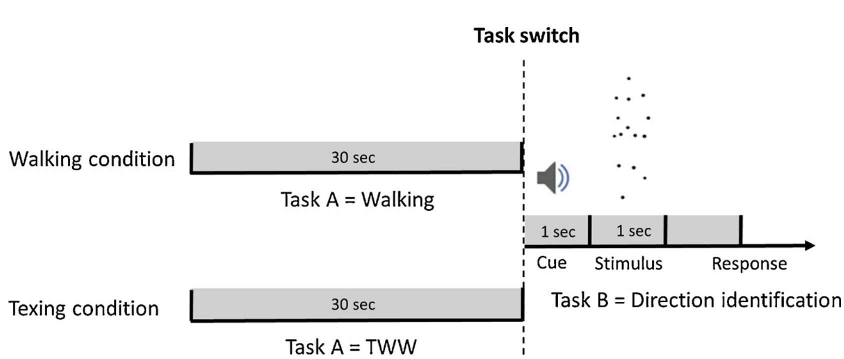

Fig. 2. Experimental design. A trial in the walking condition is composed of Task A = Walking followed by Task B and a trial in the texting condition is composed of Task A = TWW followed by Task B.

(Luck, 2005) and segmented to isolate the two seconds after the presentation of the walker and a corresponding two second baseline twelve seconds prior to the auditory cue to capture a walking-only baseline. The walker stimulus segments (Task B) and the baseline segments (Task A) were analyzed separately with a Fast-Fourier Transform (FFT) on 1 s epochs to obtain power values in the frequency domain. For both conditions, all post-stimulus epochs and all baseline epochs were averaged separately. As the goal of this study is to investigate the neurophysiological activity involved in task switching during texting while walking episodes, the analyses consist of condition differences (walking vs. texting) in brain-behavior correlations. More precisely, we aim at determining if the two substeps of task-set inhibition and task-set activation have a different impact on behavioral switch cost (indexed by decrease in performance). Therefore, EEG data was analyzed according to two indexes of task-related activity: alpha oscillations and cognitive engagement.

Recent research suggests that alpha oscillations do not reflect simple idling of brain areas, but possibly working memory control and active inhibition of task-irrelevant brain circuits (Klimesch, 1999; Jensen et al., 2002; Busch and Herrmann, 2003; Herrmann et al., 2004). We analyzed the alpha oscillations changes induced by the stimulus presentation by comparing the post-stimulus alpha power (8–14 Hz) and the baseline alpha power (Pfurtscheller and Aranibar, 1977; Sauseng et al., 2005) which we call the alpha ratio.

In order to estimate participant's cognitive engagement, we used the index developed by Pope et al. (Pope et al., 1995; Mikulka et al., 2002; Murata, 2005). The index is based on the rationale that beta activity reflects increases in arousal and attention while alpha and theta activity reflect decreases (Scerbo et al., 2003). It has been extensively validated through auto-adaptative simulators (Pope et al., 1995) and is considered a direct representation of cognitive engagement. We chose this index to evaluate if the subject's engagement in Task A would make TSR more difficult. The engagement index is measured using the ratio of combined power in the high-frequency beta bandwidth (14–20 Hz) divided by total power in lower-frequency alpha (8–12 Hz) and theta (4–8 Hz) components. The combined powers were calculated as the sums of powers at Cz and Pz for two reasons. First, the engagement ratio is traditionally measured at central and parietal electrode locations (Pope et al., 1995; Prinzel et al., 1995; Prinzel III et al., 2003). Second, EEG recording during walking is vulnerable to movement artefacts (Gwin et al., 2010; Cevallos et al., 2015), especially with subjects with thicker hair that can bounce slightly. We found electrodes Cz and Pz to be the most robust to these movements.

Table 1 highlights the dependent variables measures.

3. Results

3.1. Behavioral results

During their 88 trials, the 54 subjects identified the correct orientation more often when they were not texting prior to stimulus onset (83.2% vs. 79.9%) while having a comparable mean response time (2.518 s vs. 2.513 s). To compare if both groups had significantly different means for these 2 measures, traditional T-tests cannot be used given that these orientation tasks were performed repeatedly (88 trials) for each subject. Therefore, to account for this intra-subject correlation between trials we used generalized linear regression models using Proc Glimmix with the SAS 9.4 software. For both response variables (correct identification and response time), the group (Texting versus the reference category Not texting) was added as an explanatory variable and we also added a random Gaussian intercept for each subject to account for the intra-subject correlation. We note that since the response variable, indicating for each trial if the subject correctly identified the orientation, is binary, a logit link function was used for this regression model (also frequently called logistic regression with random effects). These analyses indeed revealed that the odds of having a correct response is significantly lower during the texting trials (Odds ratio = 0.77; $T = -3.12$; $p = 0.001$), but not the mean response time ($\beta = -0.005$; $T = -0.26$; $p = 0.799$).

The switch cost is generally measured as the difference in response time and/or percentage of correct responses between switch trials and non-switch trials (Monsell, 2003). Different performance ratios, such as the Inverse Efficiency Score (IES) (Townsend and Ashby, 1983), are commonly used in cognitive psychology to combine reaction time and percentage of correct responses. It is particularly useful when there is a trade-off between speed and accuracy. Such an approach combining accuracy and response time was used in this study. Therefore, to adequately compare the two conditions, we thus modeled the probability of being accurate for each individual trial (getting the correct answer) using a logistic regression where the response time was used as a control variable. Again, since each subject was involved in 88 trials, individual random intercepts for each subject were also added to the logistic regression model to account for possible intra-subject correlations between trials. This mixed effects logistic regression shows a significant condition effect since the estimated odds of getting a correct answer in Task B (orientation identification) is 18.9% smaller when subjects were texting prior to stimulus onset (Odds ratio = .811; $T = -2.46$; $p = .014$).

Fig. 3 illustrates the differences between the two conditions: The probability of getting a correct answer is systematically lower when TWW for any response time.

3.2. EEG results

EEG recordings performed while the participant is moving often contain more artefacts due to sweating and facial muscle contractions leading to higher rates of data exclusion (de Morree and Marcora, 2010; Gwin et al., 2010). In our case, EEG data from 29 participants were excluded because of equipment malfunction, excessive sweating artefacts or movement artefacts due to walking, or improper equipment adjustment, leaving 25 participants for the EEG analysis. These exclusions were determined prior to the behavioral analyses and should therefore not impact the results.

Spectral plots for the alpha ratio (stimulus/baseline) are shown in Fig. 4. As the alpha ratio reflects task inhibition processes, differences between the two conditions were investigated regarding their effect on performance, using the same sites as in the cognitive engagement ratio (Cz, Pz). The alpha ratio being measured, for each condition, at the participant level, to compare this ratio with its corresponding performance, we aggregated performance during that condition (i.e., the percentage of correct response during the 44 trials performed under that condition).

Table 1
Dependent variable measures.

Variable	Source	Measure
Task inhibition Pfurtscheller and Aranibar (1977)	EEG (Cz and Pz)	Post-stimulus alpha power on baseline alpha power (8–14 Hz)
Cognitive engagement Pope et al. (1995)	EEG (Cz and Pz)	High-frequency beta bandwidth (14–20 Hz) divided by total power in lower-frequency alpha (8–12 Hz) and theta (4–8 Hz)
Correct response	Verbal response correctness	Binary (correct vs. incorrect)
Response time	Verbal response time	Seconds

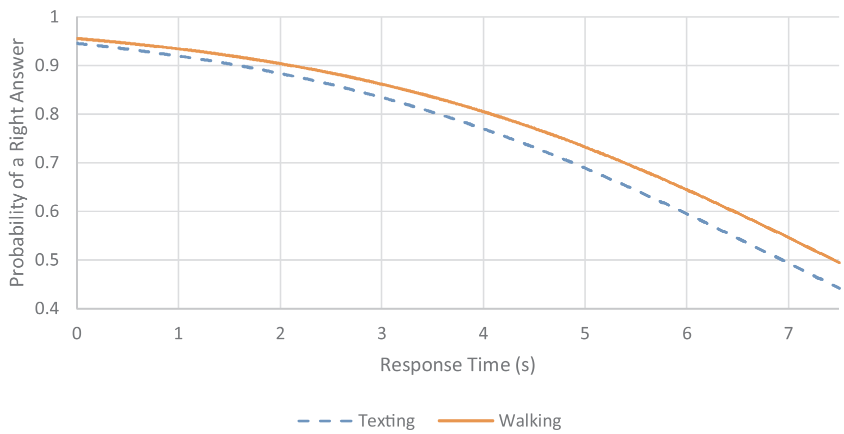

Fig. 3. Behavioral switch cost. The dashed blue line represents the probability of getting a right answer when participants are texting while walking and the solid orange line when participants are walking.

Results show that the correlations between the alpha ratio and performance differ significantly (p = .032) between the two conditions at Pz and are of opposite signs (see Table 1). This shows that the alpha ratio's impact on performance is different when the participants were texting from when they were simply walking. No significant difference was found at Cz showing that the effect was mainly located in the parietal region of the scalp. The test for the difference between two correlation coefficients is based on the z-test to compare correlation coefficients measured from the same individual proposed by Steiger (1980).

In order to investigate the effect of task engagement on switch cost, differences between the two conditions for the relation between the cognitive engagement ratio and performance were calculated. A significant difference was found between the two conditions (see Table 2).

Results show that the correlations between engagement and performance differ significantly (p = .027) when participants were walking than when they were texting while walking before task switch. The estimation of these two correlations also suggests that they are of opposite signs. The same test as above was used to compare correlation coefficients (Table 3).

Table 2
Difference between the two conditions in the relation between performance and alpha oscillations ratio.

Electrodes	Experimental condition		Test of the null hypothesis of correlation difference = 0
	Walking	Texting while walking	
	r	r	z (p-value)
Cz	−.040	−.036	.014 (.989)
Pz	.360	−.277	**2.140 (.032)**

Table 3
Difference between the two conditions (texting vs walking) in the relation between performance and cognitive engagement.

Experimental condition		Test of the null hypothesis of correlation difference = 0
Walking	Texting while walking	
r	r	z (p-value)
−.326	.236	2.20 (.027)

4. Discussion

The aim of the present study was to investigate the cognitive and attentional processes underlying switch cost during texting while walking. The behavioral results indicate that the experimental manipulation did induce a switch cost as participants who were texting while walking performed significantly worse in identifying the incoming walker's direction than participants who were only walking (Fig. 3). By examining the relationship between this observed switch cost and the EEG results, this study provides an initial understanding of how texting while walking interferes with a concurrent task.

Task-Set Reconfiguration involves the active update of the upcoming task-set and the inhibition of the previous task-set. The underlying sub-processes and the relative importance that these two steps

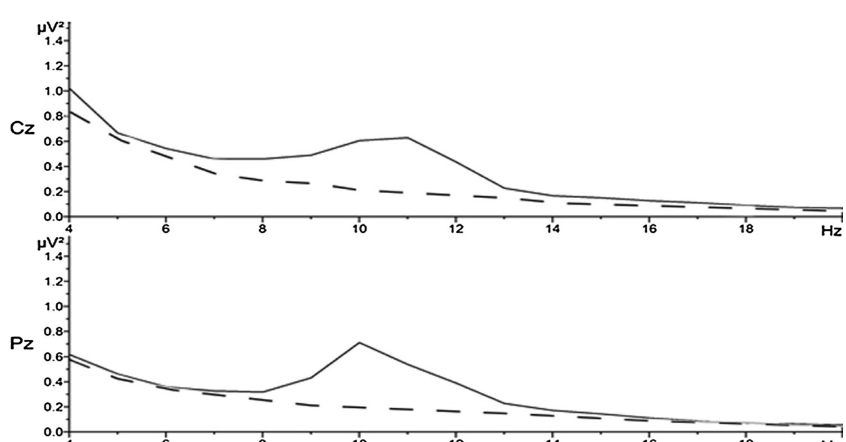

Fig. 4. Spectral power plots. Grand average of spectral power plots after presentation of the stimulus for Task A – walking (solid line) and for Task A - texting while walking (dashed line).

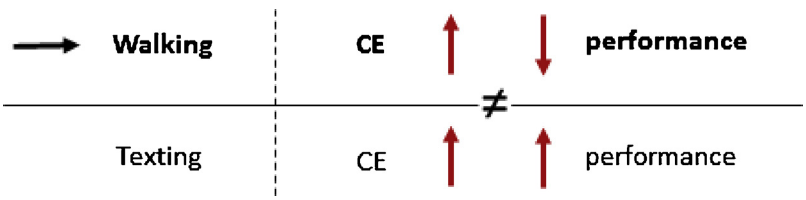

Fig. 5. Task-set activation. The relations between cognitive engagement (CE) and performance are significantly different between the two conditions. The relation is negative in the walking condition and positive in the texting condition.

play in the structure of switch cost are still being debated (De Baene et al., 2012; Li et al., 2012). The task-set inertia theory suggests that inhibition is a more crucial step and that switch cost will change more as a function of Task A than Task B (Wylie and Allport, 2000). A study by Li et al. (2012) indicates that both processes play a specific role in switch cost and can be indexed using EEG measurements. In our experimental design, the same task-set activation is required in both conditions at Task B cue (see Fig. 2). However, task-set inhibition needs to be performed only in the texting condition. As normal unobstructed walking requires the allocation of few attentional resources in healthy young participants (Yogev-Seligmann et al., 2008), Task A inhibition should not be required for Task B to be performed in the walking condition, or at least in a much less extent. As will be discussed in the next two sections, our EEG results also indicate a different impact of task-set activation and inhibition on switch cost in the two conditions.

4.1. Task-set activation

Results show that the correlations between performance and cognitive engagement during Task A differ between the two conditions and are of opposite signs (see Fig. 5).

This indicates that task engagement has a stronger impact on switch cost in the walking condition. Participants in that condition were walking on the treadmill and awaiting the next cue. However, as the response-stimulus interval was relatively long (30 s), participants may have been engaging their attentional resources in other activities. The more participants engage in parallel trains of thought while waiting for the next cue, the less attentional resources are available to engage in task-set activation processes. This leads to a decreased performance and increased switch cost. The tendency to engage in mind wandering while performing a specific task has been observed in many studies (Smallwood et al., 2003; Mason et al., 2007), even during critical tasks such as driving a car (Galéra et al., 2012) and piloting an aircraft (Jones and Endsley, 1996). The negative relation between cognitive engagement and performance may then reflect the sharing of attentional resources between mind wandering activities and task switching preparation. Additional research is needed to test the proposed mind wandering effect.

In sum, the effect of cognitive engagement is therefore in line with numerous results obtained in task-switching research, in which preparation accounts for an important part of switch cost (Rogers and Monsell, 1995b; Meiran, 1996; Monsell and Mizon, 2006; Li et al., 2012). However, the fact that the correlation is of the opposite sign in the TWW condition may indicate that task-set activation is not the most important factor for switch cost when greater task-set inhibition is also required.

4.2. Task-set inhibition

As illustrated in Fig. 6, it can be seen in our results that correlations between the parietal (Pz) alpha ratio and performance differ between the two conditions. It is of negative sign and contributing to switch cost when subjects are texting. Since the correlation is of opposite sign in the walking condition, it can be assumed that it reflects the additional resources required by task-set inhibition (only required in the TWW condition).

Alpha oscillations, particularly in the parietal region, have been linked to different executive processes in working memory (Jensen et al., 2002; Brass et al., 2005; Klimesch et al., 2006; Klimesch, 2012). More precisely, it has been postulated that event-related synchronization (ERS) is indicative of the inhibition of irrelevant information during task switching (See Klimesch et al., 2008 for a review). Although we did not use a standard measure of ERS (Sauseng et al., 2005), the alpha ratio represents a variation in alpha power after stimulus onset, and could index the inhibition taking place during task switching. As the ratio-performance correlations are significantly different and of opposite signs between the two conditions, it indicates a different account of inhibition on performance. In other words, the extent to which participants engage resources in task-set inhibition has more effect on upcoming performance when they are texting. It is not the case in the walking condition as less inhibition is required.

As mentioned, the relative contributions of task-set activation and inhibition underlying switch cost is most likely task dependent. As our results suggest that inhibition is more indicative of performance impairment when participants switch away from a TWW episode, further research is needed to investigate why it occurs. It could be hypothesized that TWW has a rather important attentional inertia because of its high interference potential. A recent study by Longman et al. (2014) suggests that attentional inertia may be an important source of residual switch cost. As predicted by multitasking and attentional sharing theories, tasks that share many characteristics are more likely to interfere with each other. It has also been suggested that task interference yields from the level of crosstalk (e.g., similarity in sensory inputs, type of information) between two tasks (Pashler, 1994). A study by Koch (2009) shows that dual-task performance is substantially worse with strong crosstalk than with weak crosstalk. In that regard, TWW has a high potential of interference with other tasks required of pedestrians, such as noticing traffic lights changes or identifying street crossing opportunities. It requires acute visual attentional resources, motor movement, language processing, and memory retrieval of information. It is therefore likely that the inhibition hurdle caused by TWW attentional inertia stems from interference and crosstalk phenomena. Investigating changes in switch cost by manipulating Task B characteristics would help to specify the nature of the interference with a variety of pedestrian behaviors.

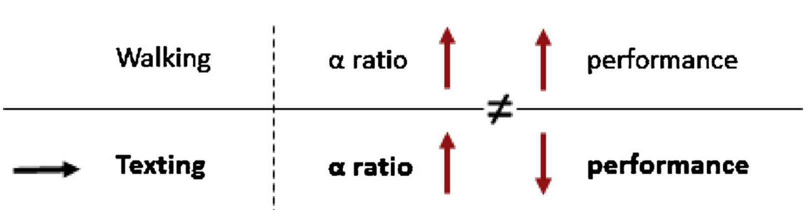

Fig. 6. Task-set inhibition. The relations between the alpha ratio and performance are significantly different between the two conditions. The relation is negative in the texting condition and positive in the walking condition.

4.3. Contributions and implications

By investigating pedestrian cognitive responses while texting, this study extends prior observational and behavioral research (Hatfield and Murphy, 2007; Nasar et al., 2008; Hyman et al., 2010) by providing an in-depth explanation of the underlying cognitive phenomena at play when pedestrians are texting while walking. Specifically, it shed light on the task switching process of pedestrians by showing how both task switching components, i.e., task-set activation and task-set inhibition, affect pedestrians when they switch their attention to their physical environment.

Nasar and Troyer (2013) suggest accidents related to cellphone usage by pedestrians is on the rise and that using a cellphone while walking put them at risk of accident, injury, or death. Results of this study show that task switching plays a role in pedestrian safety performance where it comes to texting while walking. Finding ways to help pedestrians move from one task (e.g., texting) to another task (e.g., crossing a street) by diminishing their switch cost would reduce their safety risk. This could include technological (Wang et al., 2012; Zhou, 2015; Liu et al., 2016; Rahimian et al., 2016) and public place design solutions (Nasar and Troyer, 2013). Solutions such as changes in the texture of the sidewalk along its edges, embedded traffic lights in the pavement, or alerts from incoming cars sent to pedestrians' cellphone have been proposed. For instance, Rahimian et al. (2018) empirically show the potential of alerts to improve decision making and safety of people texting while walking; thus probably helping them perform their task-set reconfiguration is a timelier manner.

5. Conclusion

The goal of the present study was to investigate the underlying cognitive and attentional effects of smartphone use by pedestrians. To our knowledge, this is the first study to observe objectively measured brain activity in a realistic context of texting while walking as, until recently, equipment allowing for recording neurophysiological data while in movement was not available. As the first study of its kind, it does come with limitations. First of all, because of equipment problems, a portion of the participants were excluded from the neurophysiological analyses. Second, we chose to use a point-like walker figure as a stimulus instead of a real person as it allowed for more control over stimuli presentation. It also improved the precision of event synchronization with the EEG data. Future work could use different stimuli (e.g., real person, cars) and tasks (e.g., street crossing decision). Third, we did not perform power analyses prior to the experimentation, the sample size was determined based on extraneous factors such as lab availability. Finally, future work could be performed in a real-world environment to increase the ecological validity of the results, e.g., moving from a treadmill walking condition to a normal over ground walking condition. As people do not walk in their activities of daily living on a treadmill, this modification in the experimental procedure is necessary to test the transferability of our results into a real-world scenario.

Taken together, results suggest that the role of task-set inhibition on switch cost is more important when subjects are texting while walking. This research contributes to a better understanding of the processes involved in texting while walking distraction and should help improve the interventions aimed at reducing the associated risks.

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