Stroop in motion: Neurodynamic modulation underlying interference control while sitting, standing, and walking

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ABSTRACT

There is conflicting evidence about how interference control in healthy adults is affected by walking as compared to standing or sitting. Although the Stroop paradigm is one of the best-studied paradigms to investigate interference control, the neurodynamics associated with the Stroop task during walking have never been studied. We investigated three Stroop tasks using variants with increasing interference levels – word-reading, ink-naming, and the switching of the two tasks, combined in a systematic dual-tasking fashion with three motor conditions – sitting, standing, and treadmill walking. Neurodynamics underlying interference control were recorded using the electroencephalogram. Worsened performance was observed for the incongruent compared to congruent trials and for the switching Stroop compared to the other two variants. The early frontocentral event-related potentials (ERPs) associated with executive functions (P2, N2) differentially signaled posture-related workloads, while the later stages of information processing indexed faster interference suppression and response selection in walking compared to static conditions. The early P2 and N2 components as well as frontocentral Theta and parietal Alpha power were sensitive to increasing workloads on the motor and cognitive systems. The distinction between the type of load (motor and cognitive) became evident only in the later posterior ERP components in which the amplitude non-uniformly reflected the relative attentional demand of a task. Our data suggest that walking might facilitate selective attention and interference control in healthy adults. Existing interpretations of ERP components recorded in stationary settings should be considered with care as they might not be directly transferable to mobile settings.

1. Introduction

Inhibitory control of attention or interference control constitutes an important aspect of executive functions that enable selective attention to some and suppression of other concurrently occurring stimuli (Diamond, 2013). Inhibitory control and selective attention are frequently assessed using the Stroop task (Stroop, 1935) in which the colored word-stimuli can either have congruent *or* incongruent features, i.e., matching *or* non-matching word meaning and ink color, respectively. When responding to the ink color of the stimuli and ignoring the word meaning (classic Stroop task; here the ink-naming task), the incongruent stimuli generally evoke longer reaction times and higher error rates compared to the congruent stimuli (MacLeod, 1991). While the two conflicting mental representations are active, the interference is produced by the prepotent tendency to respond based on the more automatic (Posner & Snyder, 1975) or faster processed (Morton & Chambers, 1973) reading as opposed to the less automatic or slower processed color naming.

The classic Stroop paradigm can be manipulated to either diminish or enhance the degree of interference and the associated mental workload. When responding is aligned with the automatic tendency, that is

according to the word meaning while ignoring the ink color (also called the reverse Stroop task, here the word-reading task), the performance difference between the congruent and the incongruent stimuli generally vanishes (Blais & Besner, 2006; Dunbar & MacLeod, 1984; Stroop, 1935), although the interference with word-reading caused by an incompatible ink color has been proven possible (Blais & Besner, 2007). The word-reading task is, therefore, relatively free of (or to a lesser degree than the ink-naming task exposed to) the interference resulting from conflicting representations of word meaning and ink color in incongruent trials. The greatest demand for attentional resources, however, can be evoked in a block of randomly switching word-reading and ink-naming trials (here the switching task), as it requires the adjustment of cognitive control on a trial-by-trial basis and is thus considered to produce the highest level of interference and requires the highest level of cognitive control (Gajewski et al., 2020).

1.1. Neurodynamic signatures of interference control

The neural information processing underlying interference control can be non-invasively assessed with millisecond precision using scalp electroencephalography (EEG). Event-related potentials (ERPs) elicited in response to task stimuli offer insights into distinguishing separate processing steps involved in interference control provoked by the Stroop paradigm. According to the conflict monitoring theory of cognitive control (Botvinick, 2007; Carter & van Veen, 2017), the anterior cingulate cortex (ACC) plays a crucial role in the top-down implementation of control detecting and processing conflict, such as the one embedded in the Stroop task. In ERP studies, the marker most robustly associated with conflict monitoring is the frontocentrally distributed N2 component, which is a negative-going component peaking between 200 and 300 ms after the stimulus presentation. This pattern has been observed in studies investigating conflict monitoring using the Stroop task (Boenke et al., 2009), the Simon task (Chen & Melara, 2009), and the Flanker task (Van Veen & Carter, 2002a), in which the conflicting trials generally exhibit greater negativity than the congruent trials. Additionally, greater N2 negativity was also observed in response inhibition demanding no-go trials in a go/no-go paradigm (Donkers & Van Boxtel, 2004), and where overcoming of previously applied inhibition, such as the negative priming (Heidlmayr et al., 2015) and task-switching (Jackson et al., 2001) are required. The neural generator of the N2 component was found residing in the ACC (Folstein & Van Petten, 2008; Van Veen & Carter, 2002b), confirming the results of several functional magnetic resonance imaging (fMRI) studies on conflict monitoring (Botvinick, 2007; Botvinick et al., 2001; Chen et al., 2013; Yeung, 2013).

As inhibitory control and working memory processes generally co-occur and support each other (Diamond, 2013), some research has also focused on the frontocentrally observed P2 component (Gajewski et al., 2020) which precedes the N2 and has been associated with task-switching (Astle et al., 2008) as well as working memory requirements of the task such as mental maintenance or stimulus-response sets (Gevins et al., 1996; McEvoy et al., 1998).

Conflict resolution has been associated with late sustained potential (LSP) which typically occurs between 500 and 800 ms post-stimulus and can either be characterized by a frontally distributed negativity (late negative complex – LNC) and/or a centroparietally distributed positivity (late positive complex – LPC). In the Stroop tasks that involve a linguistic/semantic component, a greater LSP has been observed following the presentation of conflicting stimuli and is thought to reflect mainly conflict resolution processes and response selection (Coderre et al., 2011; Donohue et al., 2016; Heidlmayr et al., 2015; Larson et al., 2009; West, 2003).

In addition to the voltage-based markers obtained in the time domain, the manipulation of the cognitive load has also been associated with certain spectral characteristics of the EEG data. The increased power of frontocentral Theta band oscillations (4–7 Hz) in response to the more demanding cognitive tasks/conditions was repeatedly demonstrated in (but not exclusively) tasks of inhibitory control, namely the Stroop task (Eschmann et al., 2018; Hanslmayr et al., 2008; Oehrn et al., 2014), Simon task (Cespón et al., 2020), and Flanker task (Cavanagh et al., 2009; Nigbur et al., 2012). In addition, frontal Theta power has been functionally associated with ERP components, such as N2 (Cavanagh & Frank, 2014; Cavanagh & Shackman, 2015) as they both appear to reflect the need for cognitive control. Complementary to Theta power increases, posterior Alpha band activity (8–12 Hz) has been shown to desynchronize leading to a decrease in power in response to the recruitment of cognitive resources (Arakaki et al., 2022; Mölle et al., 2002).

While all these studies shed light on the neural processes underlying interference control, they were all based on stationary experimental protocols that do not allow any movement of participants. In daily life, however, we often encounter situations that require interference control while standing or even walking around in our environment. Thus, the neural dynamics underlying interference control dependent on other postures than sitting (or lying in a scanner) are not well understood.

1.2. Attentional demands of postural control and locomotion

Postural control of upright stance and locomotion is ensured by the motor-cognitive system that controls balance coordination (Woollacott & Shumway-Cook, 2002) and encompasses both cortical and subcortical sources as well as cerebral and brainstem regions (Holtzer et al., 2014). Contrary to standing, postural control during walking must be maintained throughout the gait cycle while both center of mass (COM) and base of support (BOS) are moving (Woollacott & Tang, 1997) and despite external perturbations or interactions with the environment that might evoke the need for balance recovery (Perry, 2003). In addition, requirements for multisensory integration are greater while walking compared to standing because the evoked environmental and postural changes demand continuous integration of information from all sensory modalities. Thus, we can assume that attentional control must be uninterruptedly engaged to maintain a static posture, but even more attentional resources are required for walking. However, the notion that walking requires more attentional resources than standing is not fully supported by the concept of the automaticity of walking (Clark, 2015). Lau, Gwin and Ferris, 2014 showed that the connectivity of the sensorimotor network was lower during walking than during standing, possibly because locomotion is controlled by the spinal neural network to a greater degree than standing. Interestingly, the connectivity involving non-sensorimotor regions was stronger for walking than standing when participants performed a cognitive-motor dual-tasking. Taken together, the exact profile of attentional resource recruitment during standing compared to walking remains debatable.

This study, employed treadmill walking, which might differ from overground walking in some kinematic, kinetic, and electromyographic outcome measures, although the two types of walking are largely comparable (for a review see Semaan et al., 2022). Proper familiarization with the treadmill is crucial and can prevent the observed variation in some parameters, such as higher cadence, reduced stance time, and increase in hip range of motion and maximum hip flexor joint angle. Treadmill walking can increase rhythmicity (Frenkel-Toledo et al., 2005) while the motion of the belt that carries the supporting limb backward (Alton et al., 1998) could increase automaticity. Treadmill walking at a constant speed shows to be a highly automatic process that relies on cortical resources only in a limited way (Hollman et al., 2016; Simoni et al., 2013; Wrightson & Smeeton, 2017). Penati, Schieppati and Nardone (2020) employed a dual-task paradigm and showed that cognitive performance during treadmill walking is better than during overground walking. These studies suggest that treadmill walking reduces the attentional costs of walking compared to overground walking.

Taken together, if standing relies more on cortical control than walking, and treadmill walking poses a smaller attentional demand than overground walking, we expect that the comparison between standing

and treadmill walking in a cognitive-motor dual-task paradigm will maximize the effects on cortical dynamics that can be attributed to attentional resource allocation.

1.3. Postural (control) modulations of interference control

There is an ongoing debate with respect to how postural control modulates interference control. Investigations of cognitive-motor dual-tasking that report Stroop performance decrements in terms of higher error rates while standing as opposed to sitting (Rostami et al., 2020) and are in support of cognitive-motor interference (CMI; for classification see Plummer et al., 2013). The CMI presumably occurs when attentional demands of a dual-task exceed the capacity of the limited attentional reserve (Wickens, 1980) resulting in detrimental effects in at least one domain of concurrently performed tasks relative to the performance of each task separately (for reviews, see Al-Yahya et al., 2011; Leone et al., 2017). In contrast, Smith et al. (2019), and Rosenbaum et al. (2017) report in favor of the standing posture on Stroop performance, in which they observed overall faster responses, and diminished Stroop interference effect (difference between incongruent and congruent trials) compared to a sitting condition. The authors suggest that attentional resources recruited in response to the demand for maintaining a standing posture might lead to enhanced attentional selectivity (Rosenbaum et al., 2017) resulting in cognitive-motor facilitation (CMF; Plummer et al., 2013). A recent meta-analysis (Sömen, Peskar, Wollesen, Gramann & Marusic, 2023) encompassing the results of 12 experiments found a non-significant trend in favor of standing as opposed to sitting, suggesting that a standing posture is unlikely to have adverse effects on selective attention and cognitive control in healthy young adults.

Finally, some evidence suggests Stroop performance to be unaffected by postural control in sitting, standing, or walking conditions (Alderman et al., 2014; Bantoft et al., 2016; Caron et al., 2020; John et al., 2009; Ohlinger et al., 2011; Schwartz et al., 2018). However, Sosnowski (2016) found shorter RT for congruent stimuli while walking on a treadmill as compared to a sitting posture, but decreased accuracy levels indicating a speed-accuracy trade-off while dual-task walking.

The inconsistency of these behavioral results limits our understanding of how executive function and postural control in cognitive-motor dual-tasking paradigms relate and points to the necessity of exploring their respective neural dynamics to gain better insights into interference control dependent on motor condition. Additionally, the studies investigating interference control across the three postural conditions remain sparse. In view of that, the investigation of neural mechanisms involved in cognitive-motor dual-tasking as measured by the Stroop task while sitting, standing, and walking could help clarify the relationship between the cognitive and motor workloads as well as behavioral results.

1.4. Neurodynamic modulation of interference control in cognitive-motor dual-tasking paradigm

Studies investigating demands for cognitive control introduced by cognitive-motor dual-tasking, generally converge on identifying the P3 amplitude of the ERP as a typical marker associated with the cognitive workload. The P3 component, a positive potential peaking around 300 ms post-stimulus is generally considered to indicate updating and stimulus categorization (Kok, 2001), while recent evidence recognizes its role in response set selections and activation of a particular stimulus-response link (Verleger, 2020). Across a wide range of cognitive tasks, namely the visual go/no-go task (De Sanctis et al., 2014), the auditory oddball paradigm (Debener et al., 2012; Reiser et al., 2019), a three-class auditory oddball paradigm (De Vos et al., 2014), and auditory-cued task switching, the P3 amplitude at centroparietal sites was reduced during walking compared to either sitting or standing. Contrary, it was not modulated by motor task complexity or walking

speed in a visual three-class (Gramann et al., 2010) and simple visual oddball paradigm (Protzak et al., 2021). With the increasing complexity of movements, subjective workload and response times followed the same trend (Reiser et al., 2019; Reiser, Wascher, Rinkenauer & Arnau,; 2020). Moreover, in a novelty-P3 paradigm, Shaw et al. (2018) demonstrated a reduced auditory evoked P3 amplitude in response to task-irrelevant stimuli if participants were either walking as opposed to sitting or engaged in a difficult primary visual cognitive task as opposed to an easier one. The novelty-P3 component is suggested to index orienting of the attention and its amplitude depends on the availability of free or unused cognitive resources at the time, indicating that both higher movement complexity and higher cognitive engagement result in a reduced amount of unused cognitive resources.

Investigations of the neural sources involved in the generation of the P3 have identified frontal, cingulate, motor, parietal and temporal regions (Gramann et al., 2010; Makeig et al., 2004; Polich, 2007). Similarly, the regions involved in the control of movement include parietal, cingulate, sensorimotor, and frontal sources (Cortney Bradford et al., 2019; Gwin et al., 2011). The overlap of anatomical neural sources used for cognitive and motor tasks indicates they could share resources and consequently, the difference in the P3 signature between seated and walking conditions might not be surprising.

Less consensus exists with respect to whether the markers associated particularly with interference control, such as the frontocentral N2, can also be modulated by the motor load. Employing a go/no-go paradigm, De Sanctis et al. (2014) report a reduced N2 amplitude in walking as compared to sitting. On the other hand, Reiser et al. (2020) failed to detect an N2 amplitude modulation in their auditory-cued task-switching paradigm, comparing standing, walking, and walking while traversing an obstacle course.

In terms of postural modulation of spectral EEG characteristics, Reiser and colleagues (2019, 2020) report decreased event-related spectral perturbation (ERSP) in the frontal Theta range while overground walking compared to standing during both auditory oddball and auditory cue-switching tasks. They indicate a reduction of available cognitive resources during locomotive states compared to static standing might play a role in the observed effect. No effects were observed with respect to the Alpha band ERSPs.

However, no study to our knowledge has yet investigated the ERP markers and the spectral characteristics associated with the Stroop task in a mobile setting encompassing the three most commonly used postural conditions of our everyday life, namely sitting, standing, and walking. With respect to the congruency-related P3 modulation, the studies of seated conditions typically report that P3 amplitude does not differ between congruent and incongruent trials (Atkinson et al., 2003; Duncan-Johnson & Kopell, 1981; Ergen et al., 2014; Kousaie & Phillips, 2012; Rebai et al., 1997), while others report greater amplitude in congruent (Ilan & Polich, 1999; West & Alain, 1999; Zurrón et al., 2009) than incongruent trials.

1.5. Aim of the study

The primary goal of the present study was to investigate for the first time, the neural dynamics associated with the Stroop task in static and dynamic postural conditions to expand our understanding of the interplay between interference and postural control mechanisms. Due to conflicting behavioral evidence regarding the effects of a concurrently performed motor task on selective attention and inhibitory control, our goal was to systematically manipulate the difficulty of a cognitive task and a motor condition and record subjective workload, behavioral, and EEG data. We hypothesized to observe longer reaction times and higher error rates for incongruent vs. congruent trials and for the more vs. less challenging Stroop tasks characterized by higher interference and workload. Similarly, greater N2 negativity, associated with conflict monitoring, and greater LPC associated with conflict resolution were expected with the presentation of incongruent trials and in the more

demanding Stroop task(s). We also expected a decreasing amplitude for the P3 component in response to the increasing motor and cognitive demands. For frontal Theta power, we expected an increased power in response to the most demanding switching Stroop task compared to the less demanding two, and a decrease in response to walking compared to the static standing and sitting.

2. Materials and methods

2.1. Participants

Statistical power analysis was computed using G*Power 3.1.9.7. (a priori: *F*-tests; Analysis of Variance (ANOVA): repeated measures, within-factors (3 [motor conditions] x 3 [Stroop tasks]); effect size f = 0.25; Alpha error probability = 0.05; power (1-beta error probability) = 0.8; number of groups = 1; number of measurements = 9) and revealed a total of $N = 15$ subjects. Eighteen healthy participants (10 women) aged 34.0 (± 8.35) years participated in this study. All participants gave written informed consent. The participants had no history of a psychiatric or neurological disorder and were not taking any drugs known to affect cognition. They also confirmed being in good physical condition to be able to stand and walk for 60 min each without feeling notably fatigued. Additionally, participants reported no problems with color sight. Participants did not receive any compensation for their participation in the study. Due to the poor quality of EEG recordings, two participants had to be excluded from the analyses, resulting in a total sample size of 16 participants (9 women) aged 34.5 (± 8.63) years. The protocol was reviewed and approved by the National Medical Ethics Committee of the Republic of Slovenia (number 0120–76/2021/6).

2.2. Computerized Stroop task and apparatus

A modified version of the computerized Stoop task was used based on Gajewski et al. (2020). The stimuli were presented on a 19-inch monitor (refresh rate 60 Hz, resolution 1440 ×900 pixels) at a viewing distance of approximately 100 cm (with slight variations during walking). The stimuli consisted of a color word surrounded by a diamond or a square. The color words "Blue" and "Red" ("Modra" and "Rdeča" in Slovene, 5–12 mm wide x 12 mm high letters) were presented centrally against a black background and were written in one of the two colored inks. In 50% of the trials (congruent), the meaning of the written word corresponded to the color of the ink (e.g., "Blue" in blue ink), whereas in the

remaining 50% of trials (incongruent) the written word and the ink color differed (e.g., "Blue" in red ink). This resulted in 4 different stimuli, 2 of which were congruent and 2 incongruent. The color-words were surrounded by either a grey diamond or a grey square (side length 62 mm). A diamond indicated the *word-reading task* (low interference, run 1), and required participants to indicate the meaning of a written word while ignoring the ink color. A square indicated the *ink-naming* task (moderate interference, run 2), and participants were required to indicate the color of the ink, irrespective of the word meaning. In run 3, the word-reading and ink-naming cues indicated by diamond and square, respectively, were randomly varying across the trials constituting the *switching task* (high interference, run 3). Thus, difficulty in the Stroop task was increased for all participants from run 1 to run 3. The order of the motor conditions (sitting, standing, walking) was counterbalanced across the participants, whereas the order of the Stroop tasks embedded within a motor condition remained fixed as described above.

Each trial began with a grey fixation cross (bar length 9 mm) presented in the center of the screen for 1000 ms. In runs 1 and 2, a stimulus would then appear for 500 ms, followed by a black screen for 1500 ms. The response had to be given within 2000 ms after the stimulus onset or before the black screen was replaced by a fixation cross indicating the start of the next trial. The inter-trial interval for runs 1 and 2 was 3000 ms. Fig. 1 depicts an example trial sequence and timing. In run 3, stimulus presentation was prolonged to 1000 ms, and a black screen was prolonged to 2500 ms. The response in run 3 had to be given within 3500 ms following the stimulus onset. The inter-trial interval for run 3 lasted 4500 ms. Runs 1 and 2 each consisted of 144 trials – 72 congruent and 72 incongruent, with 50% of the congruent/incongruent trials requiring the response "Blue" and the other 50% requiring the response "Red". Runs 1 and 2 were each divided into 2 blocks of 72 trials, separated by a 30 s break. Run 3 consisted of 192 trials; 96 for the word-reading task and 96 for the ink-naming task. For each task embedded in the run 3, 48 trials were congruent, and 48 trials were incongruent, with 50% of congruent/incongruent trials requiring the response "Blue" and the remaining 50% requiring the response "Red". Run 3 was divided into 4 blocks of 48 trials each, separated by 30 s breaks. Between the runs, there was a 5 min break.

Stimulus onset was recorded by the CGX wireless Stim Trigger (Cognionics Inc., San Diego, CA, USA) device with millisecond precision. Two light-sensitive sensors (photodiodes) attached to the monitor could be triggered simultaneously with the onset of an experimental stimulus by the color patch switch underneath the sensors. The left or right sensor
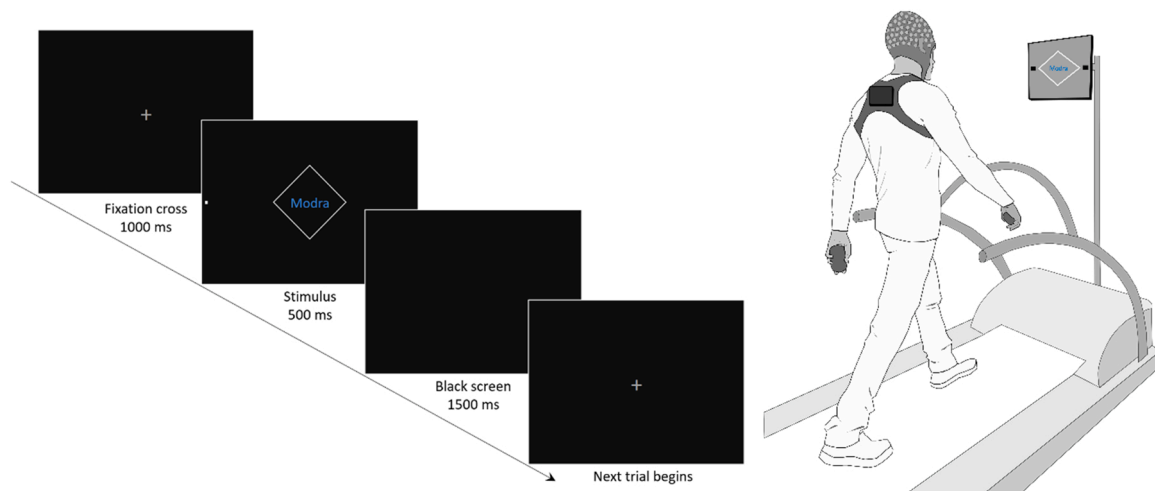

Fig. 1. (left) Trial sequence and timing used in runs 1 and 2. A diamond indicates a word-reading task. In run 3, the stimulus presentation was prolonged to 1000 ms, and a black screen was prolonged to 2500 ms. (right) The experimental setting during the walking condition. A participant is holding response devices in each hand and carrying a vest with a mounted wireless EEG amplifier (please note that electrode cables are not depicted). The 2 black squares on the presentation screen are the photodiodes.

would get triggered together with a given stimulus if the correct response to the respective stimulus was "Blue" or "Red", respectively. Responses were given by pressing one of the two ergonomically designed response buttons fixed to the left and right hands and were recorded simultaneously with the photodiode triggers. The responses "Blue" and "Red" required pressing the left- and right-handheld response buttons, respectively, using the index fingers.

Before each run, a written task instruction was delivered to participants, followed by a practice run consisting of 8 trials for runs 1 and 2, and 16 trials for run 3. During the practice, feedback regarding the correctness of their response was provided. Participants were encouraged to associate the cue with an appropriate task instruction already during runs 1 and 2 of the first-performed motor condition. They were instructed to respond both quickly and accurately.

2.3. Study design/protocol

In this cross-sectional study, the volunteers were first scheduled for a telephone screening to ensure that participation eligibility was met. After arriving at the laboratory on a testing day, participants were explained the study protocol in more detail, and written informed consent was given. This study was a 3 [motor condition] x 3 [cognitive tasks] within-subject design. In each motor condition – sitting, standing, and treadmill walking (h/p/cosmos sports & medical GmBbH, Nußdorf, Germany) at a self-selected speed, participants performed three modified Computerized Stroop tasks – word-reading, ink-naming, and instructions switching, similar to Gajewski et al. (2020). All three motor conditions were performed on the treadmill; either walking, still standing, or sitting above the treadmill on an elevated platform to achieve the same eye-level height as in the other two conditions (see Fig. 1 for the setting depiction during the walking condition). The order of the motor conditions was counterbalanced across the participants while the order of the three different Stroop tasks always remained the same within each motor condition (low interference, moderate interference, high interference). Prior to the experiment, participants were given enough time to become familiar with treadmill walking and to find a suitable pace which was then kept fixed for all walking conditions. Next, a 2 min resting state baseline EEG was recorded with both eyes closed and eyes opened. After completing the Stroop tasks in all three motor conditions, the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988) pertaining to each motor condition was applied to assess participants' perceived workload. Participants spent approximately 4 h in the laboratory.

2.4. Questionnaires and behavioural data

The subjective workload associated with each motor condition was assessed by the NASA-TLX (Hart & Staveland, 1988) and computed as an average score of the six subscales ratings, namely the mental demand, physical demand, temporal demand, performance, effort, and frustration.

For the Stroop task, response times (RT) were calculated as the time between the stimulus onset and the correct button press. The Stroop effect was computed as *incongruent RT – congruent RT*. Error rates were computed as the ratio between incorrectly answered and unanswered trials combined *and* all trials.

2.5. EEG acquisition and pre-processing

During data acquisition, Lab Streaming Layer (LSL; Kohte, 2014) was used to time-stamp and synchronize separate data streams, namely the electroencephalogram (EEG), stimulus onset markers, and response markers.

EEG was recorded using a wireless CGX Mobile-72 channel system (Cognionics Inc., San Diego, CA, USA) that allowed unrestricted mobility during data acquisition. The EEG was recorded from 72 Ag/

AgCl scalp electrodes mounted in an elastic EEG cap and positioned according to the 10–10 montage system. Reference and ground electrodes were placed on the right and left mastoids, respectively. The electrode impedance was kept below 20 kΩ for each channel and balanced across all channels within a 5 kΩ range. Data were recorded at a sampling rate of 500 Hz and digitalized at 24 bits of resolution.

The preprocessing pipeline (similar to Marusic et al. (2022)) used custom MATLAB scripts (The MathWorks, Inc.), EEGLAB (Delorme & Makeig, 2004), and ERPLAB (Lopez-Calderon & Luck, 2014). First, all continuous task-related recordings of single participants were concatenated into a single data file, downsampled to 256 Hz, high-pass filtered at 1 Hz, and 50 Hz line noise removed using the ZapLine method (Cheveigné, 2020). The ZapLine method is combining spectral and spatial filtering in such a way that it attains perfect artifact rejection while minimizing deleterious effects (Cheveigne, 2020). As such it was considered the best solution for avoiding data loss while removing spectrally overlapping noise. After initial data inspection, ZapLine spectral power plot revealed a conspicuously sharp noise-like peak at 12 Hz and its harmonics, which were removed in the second iteration of the ZapLine procedure (see Fig. S1 of Supplementary Materials).

Following ZapLine, we re-referenced the signal to the average reference, applied the automatic bad channel detection algorithm, and interpolated these channels using spherical spline interpolation. For some participants, additional bad channels were manually removed and interpolated as a trade-off for increasing the signal-to-noise ratio and preventing extensive ERP epoch rejection due to noise at a later stage. The indices (labels) of both automatically and manually rejected channels were saved. To avoid bad channels impacting the average reference, we first identified bad channels, returned to the ZapLine cleaned EEG data file, removed and subsequently interpolated the identified bad channels, followed by average re-referencing.

Continuous data were then inspected in the time domain and segments of data contaminated by muscle artifacts and other major disruptions were rejected. Next, we applied the Adaptive Mixture Independent Component Analysis (AMICA; Palmer et al., 2011) while setting the number of iterations to 2000 and reducing data rank per subject by the total number of channels interpolated plus one accounting for average re-referencing. The cortical origins of independent components were estimated using single equivalent dipole models as implemented in the DIPFIT plugin with default settings. Lastly, independent components were labeled using the ICLabel plugin (Pion-Tonachini et al., 2019).

After obtaining a single independent component solution per subject on concatenated dataset encompassing all experimental conditions, we returned to the 9 individual data files (3 [motor conditions] x 3 [Stroop tasks]). The separate data files underwent the same operations as described above, namely, downsampling to 256 Hz, high-pass filtering at 1 Hz, 50- and 12-Hz ZapLine, interpolation of bad channels (detected by the initial automated and manual procedure in the continuous concatenated file), and average re-referencing. Next, a subject's independent component values were copied to the individual files. Independent components labeled as "eye" according to ICLabel with a threshold $\geq$ 85% were automatically rejected. Components expressing clear horizontal or vertical eye-movement topography, spectral plot, time-domain signature, and to a lesser degree also dipole source location, but failed to reach the 85% threshold for automated rejection, were rejected manually after a careful inspection. This resulted in the removal of $M = 2.94$ ($SD =0.77$) ICs per subject. No other components were rejected.

2.6. ERP analysis and peak extraction

After the preprocessing, a single-subject stimulus-locked ERP analysis was computed. Data were epoched to [− 200 800] ms intervals surrounding the stimulus onset, and epochs exceeding a threshold of 100 μV were rejected (on average 12.3% of trials were rejected, $SD = 12.4$%;

rejection rates separated per condition are described in Table S1 of the Supplementary Materials). Averaged single-subject ERPs were computed for each type of congruency-word combination (congruent-blue, incongruent-blue, congruent-red, and incongruent-red).

The FCz electrode was used to extract *the peak amplitude* and latency of the P2 [110–200 ms] and N2 [180–320 ms] components within the denoted time ranges. Consistent with other studies using the same paradigm (Gajewski et al., 2020; Gajewski & Falkenstein, 2015), the selection of the respective time windows for peak detection and extraction was based on visual inspection and approximate x-axis zero-crossings of the grand average waveform (across all subjects and conditions; see Fig. S2 of Supplementary Material for the Grand average waveforms). The component-specific time windows were applied across subjects and conditions; the P2 and N2 amplitude values were detected within the predetermined time windows and their peak amplitudes were computed by averaging amplitude values in the range $[-2, +2]$ sampling points around the maximum peak amplitude which equated to the average amplitude value of 19.5 ms around the peak (Gramann et al., 2010).

The Pz electrode was used to extract the *mean amplitudes* of the LPC and P3. The LPC was extracted as the mean amplitudes over each of three consecutive 100 ms long time windows in the 500–800 ms time range (Liotti et al., 2000). The time window for LPC extraction was based on previous literature (Heidlmayr et al., 2020). Lastly, the cognitive workload-related P3 component was extracted as the mean amplitude across a 270–400 ms time range. The time window for this component was based on the visual inspection of the grand average waveform (across participants and conditions, see Fig. S2 of the Supplementary Materials); the lower window boundary was set at the trough between the second and the third peak, while the upper window boundary was set to 400 ms to ensure segregation with the later occurring effects (LPC).

Peaks detected based on the blind automated peak detection algorithm within these time windows were visually examined on a single-subject level. For the P2, one subject consistently displayed two peaks within the predetermined time window [110, 200 ms]. Of the two peaks, the later-occurring was chosen by the automated algorithm in 16/18 conditions (3 [motor condition] x 3 [Stroop task] x 2 [congruency]); the peaks in the remaining two conditions, however, deviated more than 2 SD from the mean latency ($M = 178$, $SD = 19.3$), which motivated the narrowing of the automated peak detection window for this subject to 140–200 ms and imposing detection of the later-occurring peaks in the two conditions. Similarly, the automatic detection of the N2 peak was corrected in three subjects by narrowing the time window as follows: to 180–270 ms to impose detection of an earlier occurring peak across all conditions which was by default chosen by the automated pipeline in 12/18 cases over the later occurring one; to 180–290 ms to impose detection of a peak instead of the following slope; to 230–320 ms to ensure peak is detected rather than a preceding slope. To improve automated peak detection, the time window narrowing approach was chosen instead of the manual peak re-locating approach as it allows objective reporting and reproducibility. It is important to note that the windows' width was not modified more than deemed necessary to achieve consistent peak detection and avoid peak latency disparity in highly variable EEG data across participants.

Upon peak extraction, the P2-N2 was computed as peak-to-trough amplitude difference [*N2 – P2*], for the purpose of comparing results with Gajewski et al. (2020) who employed a similar Stroop task.

2.7. ERSP analysis and spectral power calculation

For ERSP analysis, event-related data were epoched to [− 900 2700] ms intervals surrounding the stimulus onset. Power estimates were decibel-normalized per condition and subject using the entire frequency-specific pre-stimulus baseline interval [− 900 0]. Default EEGLAB settings for the wavelet cycles were applied [*3 08*] while the frequency

limits were set to 3.5–30 Hz using a 0.5 Hz resolution resulting in 53 output frequencies. Theta and Alpha band ERSPs were extracted from FCz and Pz electrodes, respectively. According to Reiser et al. (2020), Theta activity was calculated as the mean power of frequencies between 5 and 6 Hz, while Alpha activity encompassed frequencies between 9 and 11 Hz. The grand average power peak for each frequency band was calculated separately as the mean across all conditions and subjects. The frontal Theta power for each subject and condition was extracted as the mean power between 255 and 355 ms post-stimulus (corresponding to ± 50 ms interval around the grand average), while in the Alpha range the power was averaged between 310 and 510 ms post-stimulus (corresponding to ± 100 ms interval surrounding the grand average).

2.8. Statistical analysis

Statistical analyses were performed using SPSS software version 28.0 (IBM, Chicago, IL) using repeated measures ANOVA (rmANOVA) design. The average NASA-TLX was analyzed using one-factorial rmANOVA regarding the motor condition (sitting, standing, walking). Behavioral data (RTs and error rates) and ERP measures were subjected to 3 (motor condition: sitting, standing, walking) x 3 (Stroop task: word-reading, ink-naming, switching) x 2 (congruency: congruent, incongruent) rmANOVA design. The Stroop effect for reaction times as well as ERSPs for Theta and Alpha power was analyzed using 3 (motor condition: sitting, standing, walking) x 3 (Stroop task: work-reading, ink-naming, switching) rmANOVAs. In case of violation of the covariance assumption (sphericity), the Greenhouse-Geiser correction was applied (indicated by (GG)). In case of a significant interaction, simple effects were investigated. The Alpha level was kept at 0.05, except where post hoc pairwise comparisons were performed, a Bonferroni correction was applied to avoid false positives. Due to the partially exploratory nature of the investigation of neurodynamic markers in the field of interference control in mobile settings, also non-significant trends ($0.05 < p < .10$) are reported. Effect sizes are reported as adjusted partial eta squared ($adj\eta_p^2$; Mordkoff, 2019; Reiser et al., 2020). Using Pearson correlation coefficients we investigated the association between (a) reaction times and interference control-related neurodynamic markers, namely the N2 and the LPC, (b) Theta power and N2 amplitude, as well as (c) Theta and Alpha power.

3. Results

3.1. Questionnaire measures: NASA-TLX

The rmANOVA for NASA-TLX average scores showed a significant main effect of motor condition ($F(2,30) = 6.51$, $p = .004$, $adj\eta_p^2 = .26$). The Bonferroni-corrected pairwise comparisons revealed that the average subjective workload was higher in standing ($M = 9.56$, $SE = 1.02$) compared to both sitting ($M = 7.28$, $SE = 0.70$, $p = .046$) and walking ($M = 7.16$, $SE = 0.74$, $p = .017$). Fig. 2 depicts NASA-TLX ratings separated per subscale and motor condition.

3.2. Behavioral measures: walking speed, RT, error rates, Stroop effect

The mean self-selected walking speed was $M = 0$0.91 m/s, $SD = 0.14$ m/s, ranging between 0.6 and 3.8 m/s.

For RTs, the $3 \times 3 \times 2$ rmANOVA revealed significant main effects of the Stroop task ($F(1.1, 15.9) = 108.8$, $p_{(GG)} < 0.001$, $adj\eta_p^2 = .87$), congruency ($F(1,15) = 48.5$, $p < .001$, $adj\eta_p^2 = .75$), as well as the Stroop*congruency interaction ($F(1.2, 18.2) = 32.9$, $p_{(GG)} < 0.001$, $adj\eta_p^2 = .67$). A trend was observed for motor*congruency interaction ($F(2, 30) = 2.61$, $p = .09$, $adj\eta_p^2 = .09$), while no effects were observed for motor condition ($F(2, 30) = 0.53$, $p = .59$, $adj\eta_p^2 = -.03$), motor*Stroop interaction $F(1.9, 29) = 0.49$, $p = .61$, $adj\eta_p^2 = -.03$), and
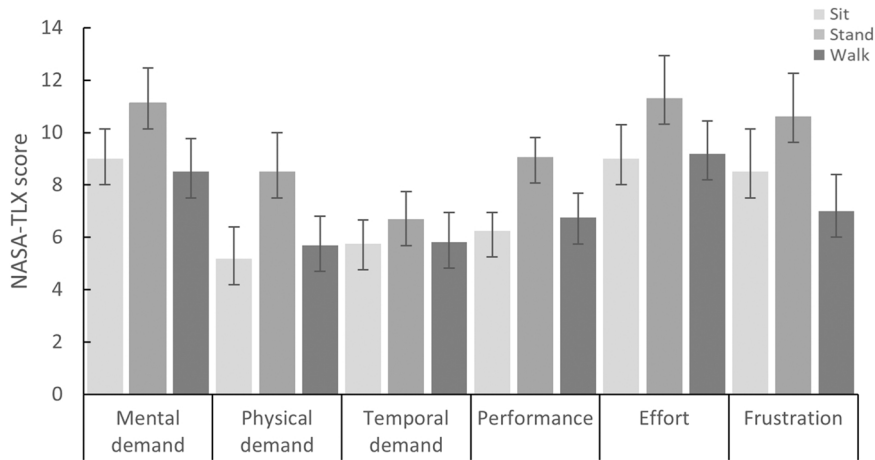
Fig. 2. Mean NASA-TLX subscale ratings separated per motor conditions (sit, stand, walk). The vertical lines denote standard error (SE).

motor*Stroop*congruency interaction $F(2.2, 32.9) = 2.39$, $p_{(GG)} = 0.103$, $adj\eta_p^2 = .08$). Data for each Stroop-congruency combination were pooled across motor conditions and Bonferroni-corrected one-way ANOVAs were performed for each level of Stroop task and congruency to investigate simple effects. Results show significantly shorter RTs for congruent than the incongruent trials in the word-reading (congruent: $M = 439.7$, $SE = 15.9$; incongruent: $M = 474.8$, $SE = 19.3$; $F(1, 15) = 30.4$, $p < .001$), ink-naming (congruent: $M = 402.5$, $SE = 17.5$; incongruent: $M = 457$, $SE = 29.4$; $F(1, 15) = 17.3$, $p < .001$), and switching task (congruent: $M = 820.6$, $SE = 54.5$; incongruent: $M = 1077.6$, $SE = 65.5$; $F(1, 15) = 43.1$, $p < .001$). For congruent trials, simple effects revealed that the RTs for the three Stroop tasks differed ($F(1.03, 15.4) = 67.03$,

$p < .001$), and Bonferroni corrected pairwise comparisons showed the RT of the ink-naming task were shorter than RT of the word-reading task ($p < .001$) and of the switching task ($p < .001$), while the RT of the word-reading were also shorter than RT of the switching task ($p < .001$). For the incongruent trials, the RTs across the Stroop tasks differed ($F(1.1, 16.8) = 124.8$, $p < .001$) and Bonferroni corrected pairwise comparisons showed the switching task had significantly longer RTs compared to the word-reading ($p < .001$) and the ink-naming task ($p < .001$). The mean RTs are visually displayed in Fig. 3 *(top)*.

Similarly, error rates showed significant main effects of the Stroop task ($F(2, 30) = 15.8$, $p < .001$, $adj\eta_p^2 = .48$), congruency ($F(1, 15) = 31.8$, $p < .001$, $adj\eta_p^2 = .66$), as well as Stroop*congruency interaction
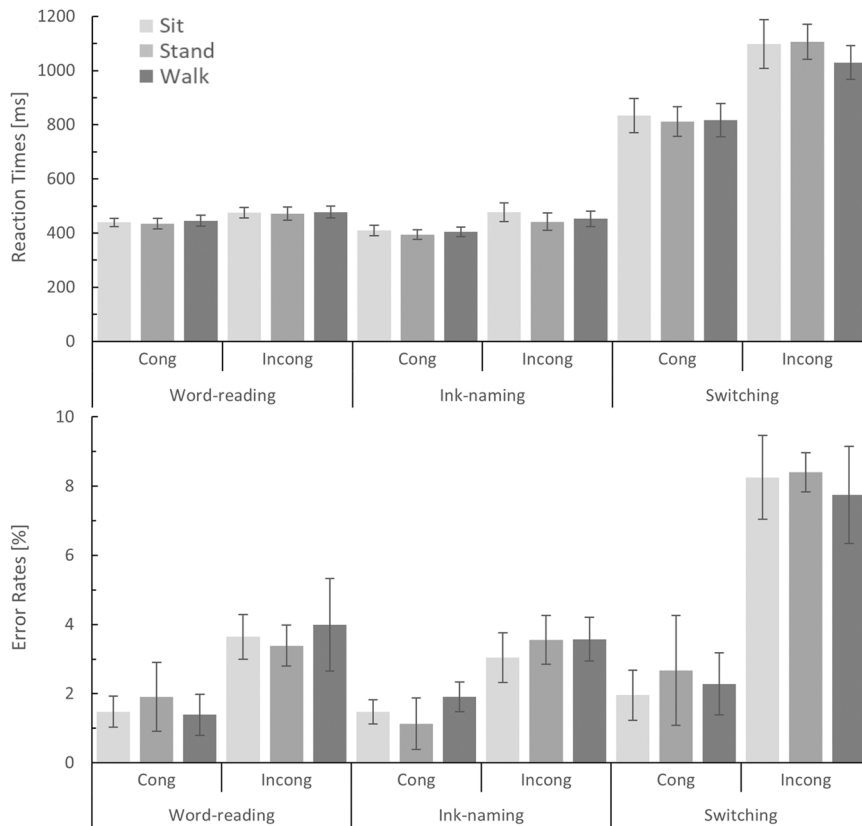

Fig. 3. Mean reaction times (top) and error rates (bottom) separated per motor condition, Stroop task, and congruency. The vertical lines denote the standard error (SE). Sit, stand, and walk denote motor conditions; word-reading, ink-naming, and switching define the Stroop task; Cong and Incong refer to congruent and incongruent trials, respectively.

$(F(2, 30) = 7.7, p < .002, adj\eta_p^2 = .30)$, while no effects were observed for the motor condition ($F(2, 30) = 0.08, p = .92, adj\eta_p^2 = -.06$), motor*Stroop interaction ($F(2.1, 31.3) = 0.40, p_{(GG)} = 0.81, adj\eta_p^2 = -.04$), motor*congruency interaction $F(2, 30) = 0.02, p = .98, adj\eta_p^2 = -.07$), and motor*Stroop*congruency interaction $F(4, 60) = 0.51$, $p = .73, adj\eta_p^2 = -.03$).Simple effects were investigated following the above-described procedure. The error rates were consistently lower for congruent as opposed to incongruent trials in the word-reading (congruent: $M = 1.59, SE = 0.35$; incongruent: $M = 3.67, SE = 0.80; F$ $(1, 15) = 11.05, p < .01$), ink-naming (congruent: $M = 1.51, SE = 0.29$; incongruent: $M = 3.39, SE = 0.56; F(1, 15) = 12.6, p < .01$), and switching task (congruent: $M = 2.30, SE = 0.58$; incongruent: $M = 8.13$, $SE = 1.20; F(1, 15) = 21.1, p < .001$). For congruent trials, error rates between the three Stroop tasks did not differ ($F(1.5, 21.7) = 1.85$, $p = .174$). However, for the incongruent trials, the error rates differed between Stroop tasks ($F(2, 30) = 13.6, p < .001$) and Bonferroni corrected pairwise comparisons revealed they were greater in the switching task compared to both word-reading ($p < .01$) and ink-naming ($p < .001$) tasks. Fig. 3 (bottom) displays the mean error rates.

For the Stroop effect, 3×3 rmANOVA revealed a main effect of the Stroop task ($F(1.2, 18.2) = 32.9, p_{(GG)} < 0.001, adj\eta_p^2 = .67$) and Bonferroni-corrected pairwise comparisons revealed that the Stroop effect was significantly larger in the switching task ($M = 257.0, SE = 39.2$) compared to both the word-reading ($M = 35.0, SE = 6.35$, $p < .001$) and the ink-naming ($M = 54.5, SE = 13.1, p < .001$) tasks. Also, a nonsignificant trend for the main effect of motor condition was observed ($F(2, 30) = 2.6, p = .09, adj\eta_p^2 = .09$), suggesting a potentially smaller Stroop effect while walking ($M = 97.5, SE = 11.4$) compared to sitting ($M = 122.0, SE = 22.4$) and standing ($M = 127.0, SE = 19.6$) (see Fig. 4). The motor*Stroop interaction (did not reach significance $F(2.19, 32.9) = 2.39, p_{(GG)} = 0.103, adj\eta_p^2 = .08$).

3.3. EEG measures

3.3.1. ERP: frontocentral P2 and N2

In the 3×3 x 2 rmANOVA, the frontocentral P2 amplitude revealed main effects of motor condition ($F(2, 30) = 9.06, p < .001, adj\eta_p^2 = .33$) and Stroop task ($F(2, 30) = 9.42, p = .001, adj\eta_p^2 = .34$). Bonferroni corrected pairwise comparisons for the motor condition showed greater amplitude in walking ($M = 3.48, SE = 0.60$) compared to both sitting ($M = 3.11, SE = 0.61, p = .041$) and standing ($M = 2.80, SE = 0.67$, $p = .003$), while for the Stroop tasks, the greater amplitude was observed in the switching task ($M = 3.55, SE = 0.66$) compared to both word-reading ($M = 3.05, SE = 0.61, p = .014$) and ink-naming tasks ($M = 2.78, SE = 0.61, p = .003$). The grand average ERPs at FCz are depicted in Fig. 4, separate for the motor condition (top) and Stroop task (bottom).

For the P2 latency, rmANOVA revealed a main effect of the Stroop task ($F(2, 30) = 7.05, p < .01, adj\eta_p^2 = .27$) and Bonferroni corrected pairwise comparisons showed shorter latency for the word-reading task

$(M = 147.4, SE = 4.07)$ compared to both the ink-naming ($M = 153,9, SE = 5.12, p < .01$) and the switching task ($M = 153.2, SE = 5.08$, $p = .048$). The rmANOVA results for the P2 component can be found in Table 1.

In the 3×3 x 2 rmANOVA, the N2 amplitude returned significant effect of the Stroop task ($F(2, 30) = 18.81, p < .001, adj\eta_p^2 = .53$). Bonferroni-corrected pairwise comparisons showed that all three Stroop tasks differed; the N2 negative deflection in the word-reading ($M = -3.51, SE = 0.47$) was greater than in the ink-naming ($M = -2.79, SE = 0.39, p = .019$) and the switching task ($M = -2.19, SE = 0.39$, $p < .001$), while the N2 deflections were also greater in the ink-naming compared to the switching task ($p = .031$). Fig. 5 (bottom) depicts the grand average ERPs separate for the Stroop tasks.

The N2 latency did not significantly differ between experimental conditions. The rmANOVA results for the N2 component can be found in Table 2.

The 3×3 x 2 rmANOVA for the P2-N2 peak-to-trough amplitude yielded a significant main effect of the Stroop task ($F(2, 30) = 13.84$, $p < .001, adj\eta_p^2 = .45$), and Bonferroni corrected pairwise comparisons showed that in the word-reading task ($M = 6.56, SE = 0.79$) the amplitude was higher compared to both the ink-naming ($M = 5.58, SE = 0.75$, $p < .001$) and switching ($M = 5.74, SE = 0.83, p < .01$) tasks. Fig. 6 depicts P2-N2 amplitudes separate for Stroop tasks. The rmANOVA results for the P2-N2 peak-to-trough amplitude can be found in Table 3.

3.3.2. ERP: parietal P3 and late positive complex (LPC)

For the P3 mean amplitude, 3×3 x 2 rmANOVA returned a significant main effect of the motor condition ($F(2, 30) = 3.71, p = .036$, $adj\eta_p^2 = .14$) and Stroop task ($F(2, 30) = 3.97, p = .030, adj\eta_p^2 = .16$). Pairwise comparisons for motor conditions did not survive the Bonferroni correction and showed a non-significant trend of greater amplitude while sitting ($M = 3.72, SE = 0.53$) compared to standing ($M = 3.39, SE = 0.54, p = .087$) and walking ($M = 3.22, SE = 0.57, p = .069$). For the Stroop task, the mean amplitude in the ink-naming task ($M = 3.92, SE = 0.66$) proved greater than in the word-reading task ($M = 3.06, SE = 0.54, p = .009$), but not significantly different from the switching task ($M = 3.35, SE = 0.49$). Fig. 7 depicts the grand average ERPs separate for the motor condition (top) and Stroop task (bottom). The rmANOVA results for the P3 amplitude can be found in Table 4.

For the mean amplitude of the LPC between 500 and 600 ms post-stimulus, rmANOVA returned the main effect of motor condition ($F(2, 30) = 6.75, p < .01, adj\eta_p^2 = .26$) and Stroop task ($F(1.3, 19.3) = 8.58$,
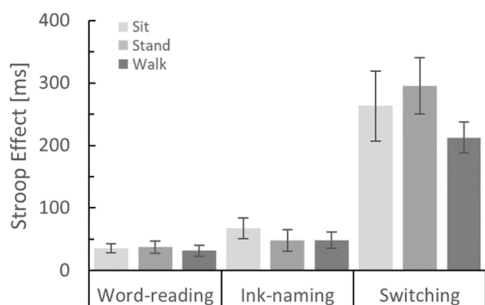

Fig. 4. The Stroop effect separated per motor condition and Stroop task. For abbreviations, see Fig. 3. The vertical lines denote the standard error (SE).

Table 1
Three-way repeated measures ANOVA of frontocentral P2 amplitude and latency.

COMPONENT	FACTOR	df_1, df_2	F	p	$adj\eta_p^2$
P2 amplitude	Motor	2, 30	9.055	< 0.001 *	0.33
	Stroop	2, 30	9.418	< 0.001 *	0.34
	Congruency	1, 15	1.935	0.184	0.06
	M*S	4, 60	0.994	0.418	0.00
	M*C	2, 30	0.522	0.598	-0.03
	S*C	2, 30	0.494	0.615	-0.03
	M*S*C	4, 60	0.081	0.988	-0.06
P2 latency	Motor	1.4, 20.4	0.192	0.741(GG)	-0.05
	Stroop	2, 30	7.049	0.003 *	0.27
	Congruency	1, 15	0.204	0.658	-0.05
	M*S	2.8, 42.3	0.431	0.720(GG)	-0.04
	M*C	2, 30	0.067	0.936	-0.06
	S*C	2, 30	1.143	0.332	0.01
	M*S*C	2.8, 41.3	0.514	0.660(GG)	-0.03

Abbreviation: Motor – motor condition; Stroop – Stroop task; M*S – interaction between motor condition and Stroop task; M*C – interaction between motor condition and congruency; S*C – interaction between Stroop task and congruency; M*S*C – interaction between motor condition, Stroop task, and congruency.
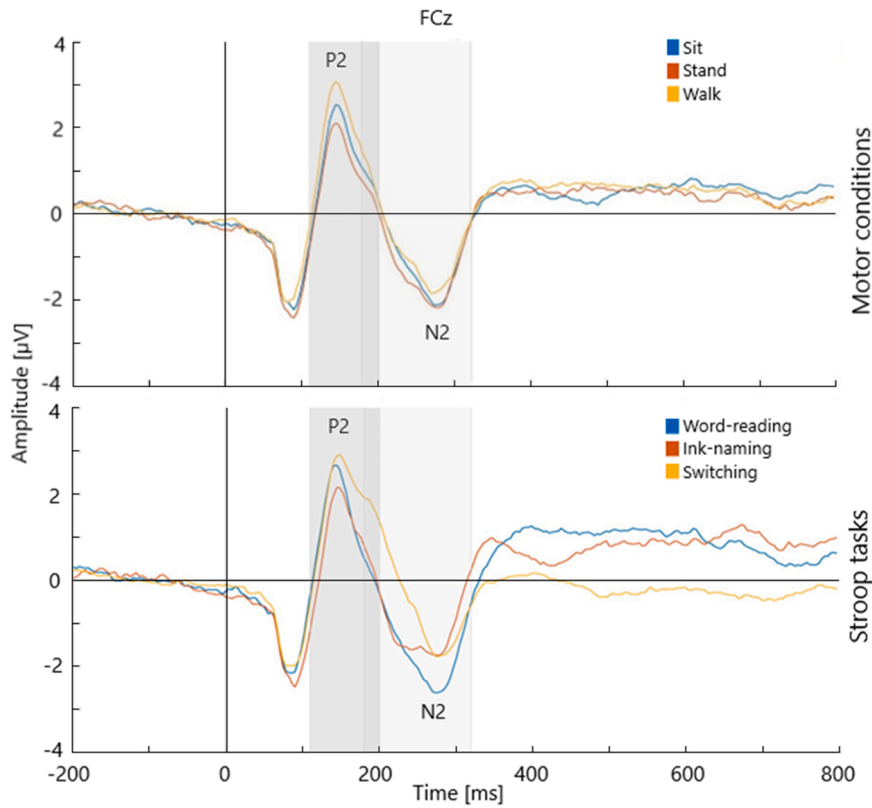
Fig. 5. Grand average ERP at FCz. ERPs are depicted as the main effects of (top) the motor condition (collapsed across Stroop tasks and congruency) and (bottom) the Stroop task (collapsed across motor conditions and congruency) and plotted as a function of amplitude [μV] over time [ms]. The P2 peak was extracted from the dark grey shaded area, [110,200] ms. The N2 peak was extracted for the light grey shaded area, [180,320] ms.

Table 2
Three-way repeated measures ANOVA of frontocentral N2 amplitude and latency.

COMPONENT	FACTOR	df_1, df_2	F	p	$adj\eta_p^2$
N2 amplitude	Motor	2, 30	1.336	0.278	0.02
	Stroop	2, 30	18.809	< 0.001 *	0.53
	Congruency	1, 15	3.752	0.072	0.15
	M*S	4, 60	2.006	0.105	0.06
	M*C	2, 30	0.790	0.463	-0.01
	S*C	1.3, 19.7	0.209	0.718(GG)	-0.05
	M*S*C	4, 60	0.128	0.972	-0.06
N2 latency	Motor	1.3, 20	0.406	0.590(GG)	-0.04
	Stroop	2, 30	1.655	0.208	0.04
	Congruency	1, 15	0.017	0.899	-0.07
	M*S	2.3, 34.2	0.963	0.402(GG)	0.00
	M*C	2, 30	0.431	0.654	-0.04
	S*C	2, 30	1.655	0.208	0.04
	M*S*C	4, 60	2.770	0.053	0.10

For abbreviations, see Table 1.

Fig. 6. The P2-N2 peak-to-trough amplitudes separated by the Stroop task. For abbreviations, see Fig. 3. The vertical lines denote the standard error (SE).

$p < .01$, $adj\eta_p^2 = .32$). Bonferroni corrected pairwise comparisons for the motor condition revealed smaller amplitude while walking ($M = 1.20$, $SE = 0.46$) as opposed to both sitting ($M = 1.88$, $SE = 0.36$, $p = .023$) and standing ($M = 1.80$, $SE = 0.42$, $p = .036$), whereas, for the Stroop task, a greater amplitude was observed for the switching task ($M = 2.41$, $SE = 0.44$) compared to both word-reading ($M = 1.41$, $SE = 0.43$, $p = .049$) and ink-naming ($M = 1.06$, $SE = 0.46$, $p = .017$) tasks. rmANOVA for the LPC between 600 and 700 ms post-stimulus returned a main effect of the Stroop task ($F(1.2, 18.2) = 9.13$, $p < .01$, $adj\eta_p^2 = .34$) and Bonferroni corrected pairwise comparisons showed greater amplitude in the switching task ($M = 1.37$, $SE = 0.41$) compared to both word-reading ($M = 0.30$, $SE = 0.37$, $p = .026$) and ink-naming ($M = 0.16$, $SE = 0.35$,
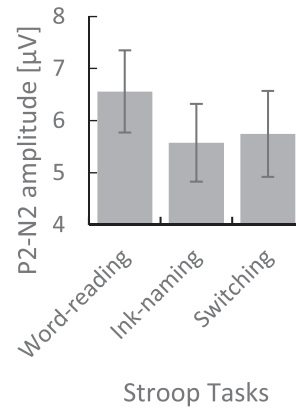
Table 3
Three-way repeated measures ANOVA of frontocentral P2-N2 peak-to-trough amplitude.

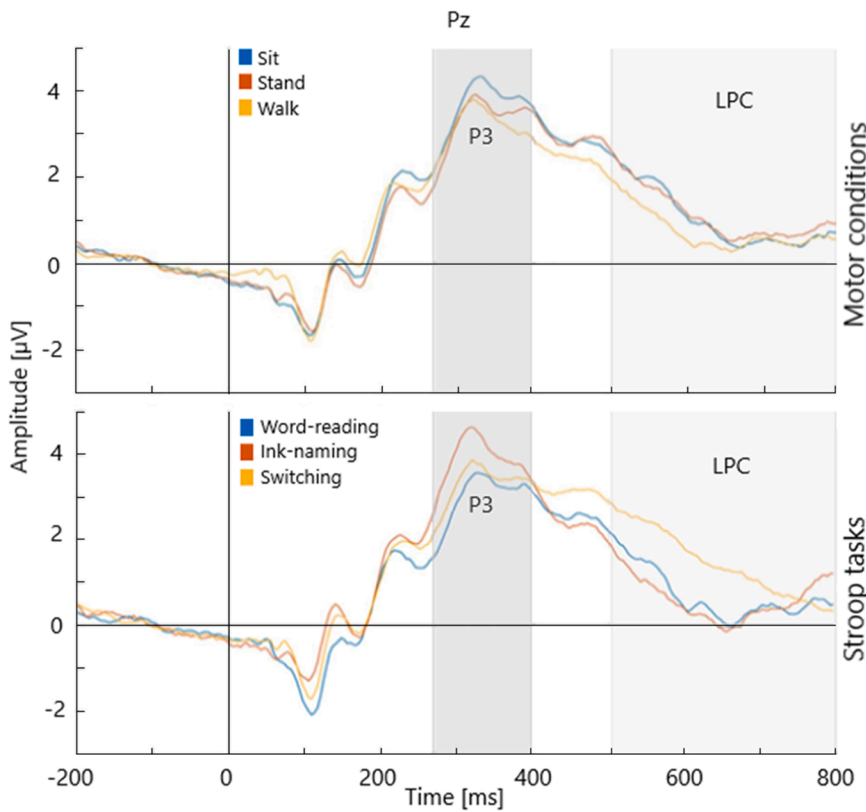| COMPONENT	FACTOR	df_1, df_2	F	p	$adj\eta_p^2$
P2-N2 amplitude	Motor	2, 30	0.531	0.593	-0.03
	Stroop	2, 30	13.839	< 0.001 *	0.45
	Congruency	1, 15	0.138	0.716	-0.06
	M*S	4, 60	0.811	0.523	-0.01
	M*C	2, 30	0.911	0.413	-0.01
	S*C	1.2, 18.6	0.071	0.844(GG)	-0.06
	M*S*C	2.6, 38.5	0.307	0.789(GG)	-0.05

For abbreviations, see Table 1.

Fig. 7. Grand average ERP at Pz. ERPs are depicted as the main effects of (top) the motor condition (collapsed across Stroop tasks and congruency) and (bottom) the Stroop task (collapsed across motor condition and congruency) and plotted as a function of amplitude [μV] over time [ms]. The P3 mean amplitude values were extracted as average amplitudes across the dark grey shaded area (270–400 ms) per subject and condition. The LPC values were extracted from the light grey shaded area (500, 800 ms) across three 100 ms long time windows per subject and condition.

Table 4
Three-way repeated measures ANOVA of parietal P3 mean amplitude.

COMPONENT	FACTOR	df_1, df_2	F	p	$adj\eta_p^2$
P3 amplitude	Motor	2, 30	3.713	0.036 *	0.14
	Stroop	2, 30	3.970	0.030 *	0.16
	Congruency	1, 15	1.463	0.245	0.03
	M*S	4, 60	1.740	0.153	0.04
	M*C	1.3, 19.4	0.454	$0.558_{(GG)}$	-0.04
	S*C	2, 30	1.377	0.268	0.02
	M*S*C	4, 60	0.154	0.960	-0.06

For abbreviations, see Table 1.

$p = .018$). Lastly, for the LPC between 700 and 800 ms post-stimulus, rmANOVA returned no significant effects. See Fig. 7 for the ERP time series of the LPC separated by the motor condition (top) and Stroop task (bottom). The rmANOVA results for the LPC mean amplitudes can be found in Table 5.

3.3.3. ERSP: frontocentral theta

The 3×3 rmANOVA for the frontocentral Theta power revealed significant main effects of the motor condition ($F(2, 30) = 10.33$, $p < .001$, $adj\eta_p^2 = .37$), Stroop task ($F(2, 30) = 20.16$, $p < .001$, $adj\eta_p^2 = .54$), as well as the motor*Stroop interaction ($F(4, 60) = 3.89$, $p = .007$, $adj\eta_p^2 = .15$). Bonferroni corrected simple effects investigated per each level of motor condition revealed that during sitting, the switching task evoked lower Theta power ($M = 1.70$, $SE =0.24$) than word-reading ($M = 3.10$, $SE = 0.28$, $p < .001$) and ink-naming tasks ($M = 2.91$, $SE =0.24$, $p = .002$). While standing, the switching task also evoked lower Theta power ($M = 1.65$, $SE =0.24$) compared to word-reading ($M = 3.35$, $SE =0.39$, $p < .001$) and ink-naming tasks ($M = 2.88$, $SE =0.32$, $p = .003$). During walking, the switching task showed lower Theta power ($M = 1.35$, $SE =0.21$) compared to the word-reading task ($M = 2.20$, $SE =0.38$, $p = .017$) while the ink-naming task ($M = 1.72$, $SE =0.32$)

Table 5
Three-way repeated measures ANOVA of the parietal mean amplitude of the late positive complex assessed across three time windows.

COMPONENT	FACTOR	df_1, df_2	F	p	$adj\eta_p^2$
LPC 500–600 amplitude	Motor	2, 30	6.750	0.004 *	0.26
	Stroop	1.3, 19.3	8.587	$0.005_{(GG)}$*	0.32
	Congruency	1, 15	0.343	0.567	-0.04
	M*S	4, 60	1.341	0.265	0.02
	M*C	1.3, 18.9	0.684	$0.452_{(GG)}$	-0.02
	S*C	2, 30	2.509	0.098	0.09
	M*S*C	4, 60	0.285	0.887	-0.05
LPC 600–700 amplitude	Motor	2, 30	1.159	0.327	0.01
	Stroop	1.2, 18.2	9.132	$0.005_{(GG)}$*	0.34
	Congruency	1, 15	0.401	0.536	-0.04
	M*S	4, 60	0.613	0.655	-0.02
	M*C	1.4, 20.9	0.673	$0.469_{(GG)}$	-0.02
	S*C	2, 30	0.482	0.622	-0.03
	M*S*C	4, 60	1.157	0.339	0.01
LPC 700–800 amplitude	Motor	2, 30	0.440	0.648	-0.04
	Stroop	1.3, 19.2	0.332	$0.625_{(GG)}$	-0.04
	Congruency	1, 15	0.010	$0.920_{(GG)}$	-0.07
	M*S	4, 60	0.347	0.845	-0.04
	M*C	1.3, 19.6	0.869	$0.391_{(GG)}$	-0.01
	S*C	1.4, 21.7	0.330	$0.653_{(GG)}$	-0.04
	M*S*C	2.1, 31.5	1.259	$0.299_{(GG)}$	0.02

For abbreviations, see Table 1.

demonstrated a trend towards lower Theta power compared to the word-reading task ($p = .06$). Bonferroni corrected simple effects investigated per each level of the Stroop task showed that performing the word-reading task while walking elicited lower Theta power compared to sitting ($p = .024$) and standing ($p = .018$). Similarly, the ink-naming task while walking elicited lower Theta power compared to sitting ($p = .005$) and standing ($p = .002$). In the switching task, no differences in Theta power between motor conditions were observed ($p > .05$). See Fig. 8 for a graphic depiction of Theta power across motor conditions and Stroop tasks. The rmANOVA results for the Theta power can be found in Table 6.

Table 6

Two-way repeated measures ANOVA of frontocentral Theta power.

MEASURE	FACTOR	df_1, df_2	F	p	$adj\eta_p^2$
Theta Power	Motor	2, 30	10.334	< 0.001 *	0.37
	Stroop	2, 30	20.161	< 0.001 *	0.54
	M*S	4, 60	3.891	0.007 *	0.15

For abbreviations, see Table 1.

3.3.4. ERSP: parietal Alpha

The 3×3 rmANOVA for the parietal Alpha power revealed a significant main effect of the motor condition ($F(2, 30) = 9.56$, $p < .001$,
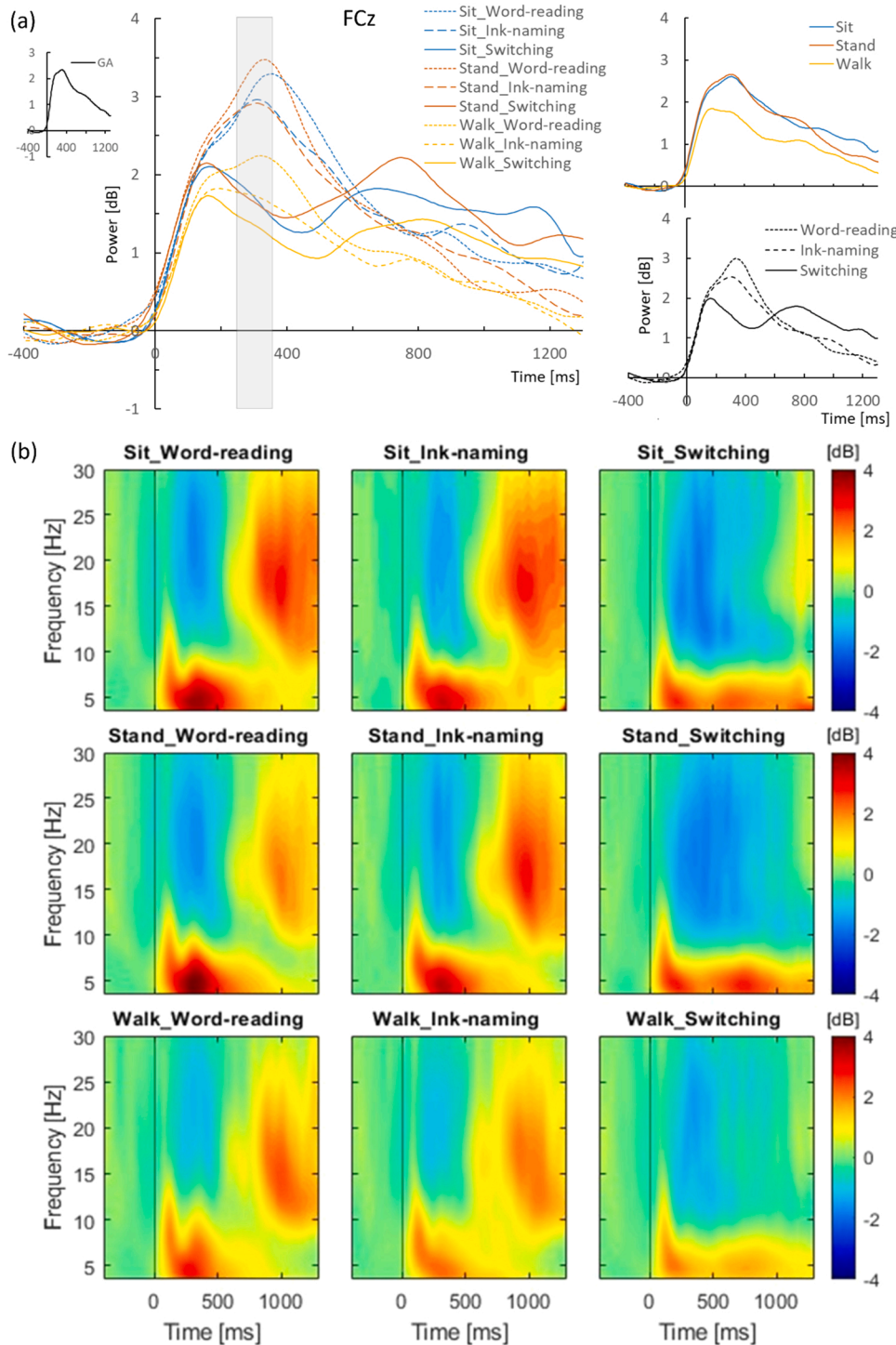

Fig. 8. Frontocentral Theta power across motor conditions and Stroop tasks. (a) top left: The grand average (GA) ERSP Theta power used to calculate the averaging window (grey shaded area in the middle plot; 305 ± 50 ms). (a) middle: Average Theta power per each motor-Stroop combination. (a) right: Averaged Theta power per (top) motor conditions and (bottom) Stroop tasks. x-axes – time in milliseconds [− 400 1300 ms], y-axes – power in decibels [dB]. (b) Averaged time-frequency plots for each motor-Stroop combination. Theta was extracted as the mean power of all frequencies between 5 and 6 Hz. Power fluctuations across conditions can be observed in Theta, Alpha, and Beta range. x-axes – time in milliseconds [− 400 1300 ms], y-axes – frequency [3.5 30 Hz].

$adj\eta_p^2 = .35$). Bonferroni corrected pairwise comparisons showed higher Alpha power during walking ($M = -0.99$, $SE = 0.33$) compared to sitting ($M = -2.57$, $SE = 0.54$, $p = .008$) and standing ($M = -1.97$, $SE = 0.46$, $p = .006$). Considering a Greenhouse Geiser correction, the main effect of the Stroop task showed a trend for significance ($F(1.195, 17.9) = 4.01$, $p = .055$, $adj\eta_p^2 = .16$) but did not survive the Bonferroni corrected pairwise comparisons at an Alpha level of $< .1$ (word-reading: $M = -1.76$, $SE = 0.43$; ink-naming $M = -1.50$, $SE = 0.41$; switching: $M = -2.28$, $SE = 0.45$). Fig. 9 offers a depiction of Theta power across motor conditions and Stroop tasks. The rmANOVA results for the Alpha power can be found in Table 7.

Table 7
Two-way repeated measures ANOVA of parietal Alpha power.

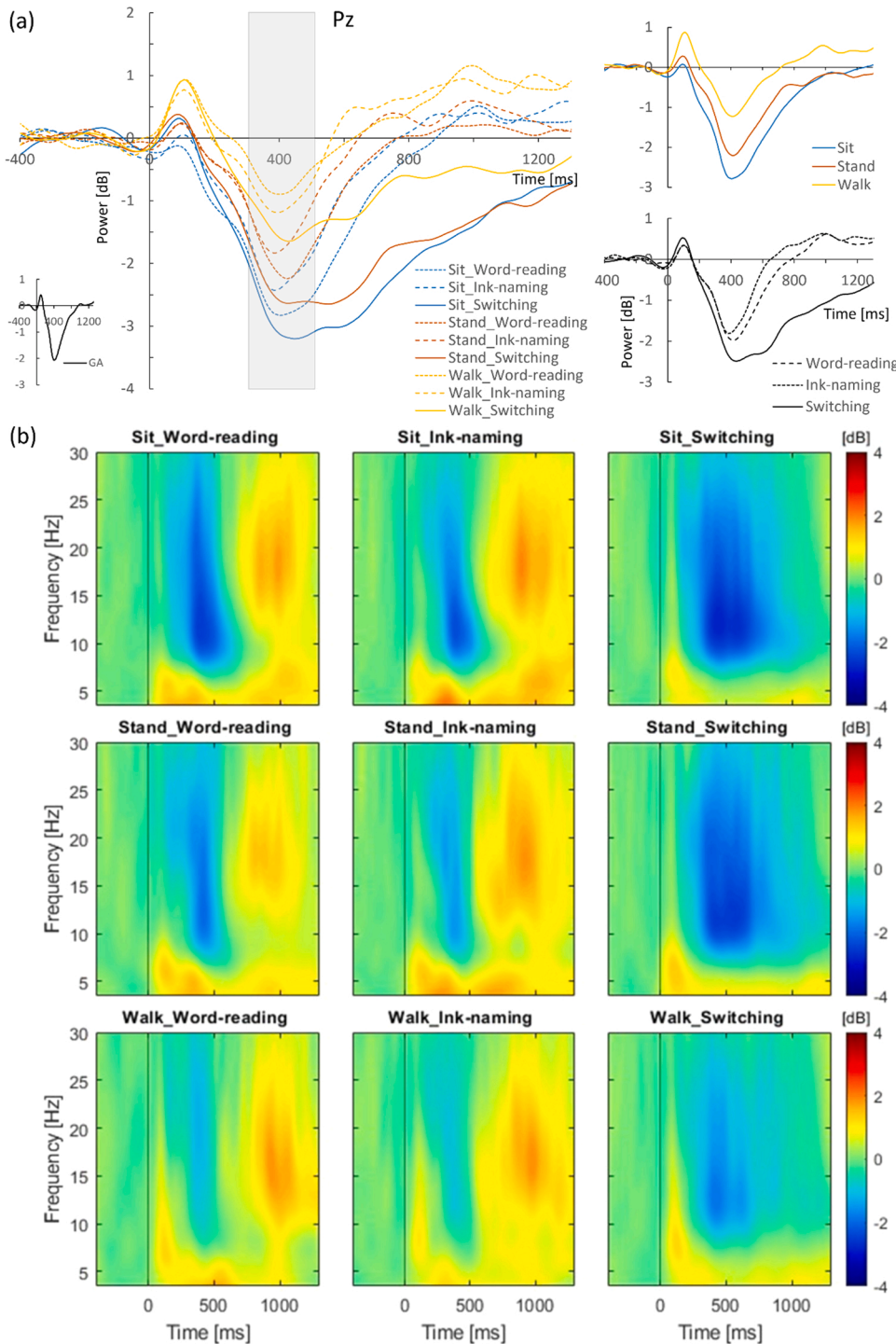| MEASURE	FACTOR	df_1, df_2	F	p	$adj\eta_p^2$
Alpha Power	Motor	2, 30	9.554	< 0.001 *	0.35
	Stroop	1.2, 17.9	4.009	0.055(GG)	0.16
	M*S	4, 60	0.794	0.534	-0.01

For abbreviations, see Table 1.

Fig. 9. Parietal Alpha power across motor conditions and Stroop tasks. (a) bottom left: The grand average (GA) ERSP Alpha power used to calculate the averaging window (grey shaded area in the middle plot; 410 ± 100 ms). (a) middle: Average Alpha power per each motor-Stroop combination. (a) right: Averaged Alpha power per (top) motor conditions and (bottom) Stroop tasks. x-axes – time in milliseconds [− 400 1300 ms], y-axes – power in decibels [dB]. (b) Averaged time-frequency plots for each motor-Stroop combination. Alpha was extracted as the mean power of all frequencies between 9 and 11 Hz. Power fluctuations across conditions can be observed in the Alpha and Beta range. x-axes – time in milliseconds [− 400 1300 ms], y-axes – frequency [3.5 30 Hz].

3.4. Correlation analyses

The N2 latency during walking was positively associated with the reaction times in the word-reading ($r(16) = 0.632$, $p = .009$) and switching tasks ($r(16) = 0.53$, $p = .035$). Non-significant trends for a positive association between N2 latencies in the word-reading task were also observed during both sitting ($r(16) = 0.49$, $p = .052$) and standing conditions ($r(16) = 0.44$, $p = .088$), and in the ink-naming task for the walking condition ($r(16) = 0.43$, $p = .096$). Conversely, the N2 amplitude was negatively associated with the reaction times in the switching task while sitting ($r(16) = -0.63$, $p = .009$), and a non-significant trend was observed in the ink-naming task while standing ($r(16) = -0.47$, $p = .62$). The LPC showed no association with reaction times in any condition.

Theta power showed a positive association with Alpha during standing in the ink-naming task ($r(16) = 0.52$, $p = .038$), and a similar trend was observed for walking while performing the word-reading task ($r(16) = 0.48$, $p = .059$). Theta power and N2 amplitude showed no association ($p > .05$).

4. Discussion

In the present study, we investigated the neural dynamics of interference control using the Stroop task while healthy adult participants were either sitting, standing, or walking on a treadmill at a self-selected speed. The main aim was to assess the interaction between cognitive and motor attentional demands by systematically manipulating the load on the motor and cognitive systems in a 3 [motor conditions] x 3 [Stroop tasks] within-subject design. The three Stroop tasks also differed in difficulty in that they required a varying amount of cognitive control. Subjective workload, reaction times, error rates, and neurophysiological indices associated with working memory, interference control, attentional resources, and mental workload were analyzed to better understand the mechanisms by which postural complexities modulate cognitive control.

4.1. Behavioral results

Overall, the behavioral results in terms of response time and accuracy showed that across all Stroop task difficulties, incongruent trials took longer to respond and were more prone to errors than congruent trials, which is in line with our hypotheses and the literature (MacLeod, 1991). While the RTs increased in the most difficult Stroop task compared to the less difficult two for both congruent and incongruent trials, this was not the case for the error rates. Accuracy remained unchanged for the congruent trials across the Stroop tasks, while it increased with increasing Stroop task difficulty for the incongruent trials. Prolonged RT and increased error rates for (particularly the conflicting stimuli in) the switching task supposedly reflect the time needed to perform an additional mental process, that is the selection of a response rule (e.g. "read the word" *or* "name the ink color") which was absent in the less challenging Stroop task variants. These results also suggest that the cognitive system involved in interference control could reflect increased mental workload in prolonged reaction times to congruent stimuli, and in prolonged reaction times *and* increased error rates to incongruent stimuli (Gajewski et al., 2020). This is further supported by the Stroop effect, a measure of interference control, which after accounting for the time needed for rule selection in the switching task, demonstrates worsening as the task difficulty increases. In other words, subtracting congruent from incongruent reaction times eliminates the effect of switching, however, the Stroop effect data demonstrate, that this measure of (pure) interference control, is nevertheless dependent on the overall difficulty of the task to some degree. As posed by Diamonds (2013), working memory and interference control can coincide or depend on one another, and our data suggest that they might tap into the same resource pool given the supra-additive effect on Stroop

effect reaction times that they express. Lastly, a non-significant trend, however, suggests that engagement in a dynamic motor task such as treadmill walking might facilitate or promote mechanisms supporting interference control. While the Stroop effect in sitting and standing postures did not show consistent trends across the three Stroop tasks (see Fig. 4), the smallest Stroop effect was consistently elicited while walking across the three Stroop tasks. A recent meta-analysis (Sömen et al., 2023) showed that the Stroop task performance in healthy adults was not differently affected by sitting or standing posture, which is also indicated by our data. Walking, which was not investigated in the respective meta-analysis, seemed to facilitate interference control in our study. The non-significant trend of motor*Stroop interaction, however, points to the necessity of further studies investigating walking-modulated interference control; for a comprehensive understanding, these trends should also be investigated in healthy older adults and/or clinical populations, such as Parkinson's disease patients, whose attentional reserve might be more prone to walking-induced depletion.

4.2. Neural markers

4.2.1. Working memory and interference control

In terms of the electroencephalographic markers, the frontocentrally distributed P2 component showed the greatest amplitude in the most attentionally demanding motor condition – walking, *and* in the most challenging cognitive condition – the switching Stroop task, while its latency was the shortest in the least difficult Stroop task. Given the association between working memory and the P2 component (Gajewski et al., 2020; Gevins et al., 1996; McEvoy et al., 1998), the observed evidence could suggest greater involvement of the working memory supporting the execution of the more difficult cognitive as well as motor tasks.

The N2 component that follows the P2 deflection at frontocentral sites is considered a typical marker associated with the conflict monitoring process of interference control (for a review, see Heidlmayr et al., 2020). In this study, all conditions elicited a clear N2 component, however, the expected N2 amplitude increase with conflicting stimuli and increasing task difficulty was not observed. Instead, the reversed pattern was evident with the most negative deflection elicited in response to the least demanding word-reading task, while the smallest amplitude was noted in the switching task. A similar trend was observed for the Theta power which, contrary to our expectations, demonstrated greater power in the two less demanding Stroop tasks compared to the most demanding switching task regardless of motor conditions. Our results may indicate that the frontocentral N2 does not unidirectionally follow the trend of exhibiting greater amplitude in response to more conflicting stimuli. Kousaie and Phillips (2012) demonstrated that the N2 responses to stimuli of varying conflicting levels – the congruent, incongruent, and neutral Stroop trials, did not differ in amplitude. Furthermore, in the Flanker task (Yeung & Cohen, 2006) it has been suggested that a larger N2 amplitude reflects increased processing of target-irrelevant information, the flankers, which indicates deterioration of attentional focus on target-relevant information. In this view, the smallest N2 amplitude elicited in response to the most challenging switching Stroop task in the present study could indicate the highest level of engaged cognitive control and focusing attention on the task-relevant information. The possibility that the task-set could change with each trial in the switching Stroop task, required the highest level of cognitive control (Gajewski et al., 2020). Given that the working memory generally co-occurs if not prerequisites the interference control (Diamond, 2013), these claims are also supported by the observed effect on the working memory-related P2 amplitude which was the highest in the most challenging cognitive and motor conditions. Although the Theta power and N2 amplitudes showed no statistical correlation, the observed effects in both measures share the direction and are characterized by large effect sizes. Future research is needed to clarify the relationship between task difficulty indicated by the behavioral results

and neurophysiological markers associated with conflict processing in mobile settings.

In view of this, the P2-N2 peak-to-trough amplitudes were additionally used as a combined index of executive function involvement, namely the working memory and interference control, following the example of Gajewski et al. (2020) who had also inspired the three-level Stroop task difficulty manipulation in this study. The trend of our results is in line with that of Gajewski et al. (2020) in which the most challenging Stroop task elicited lower P2-N2 amplitude than the least challenging Stroop task, while no effect was observed with respect to congruity. If the N2 amplitude would increase with and reflect the level of required cognitive control in response to the task at hand, the P2-N2 amplitude should have been the greatest in the most challenging switching task. This was, however, not the case neither in Gajewski et al. (2002) nor the present study. This notion provides evidence that the frontocentral N2 might not map the level of interference in a proportional unidirectional fashion.

The N2 component also exhibited a relationship with the speed of responding and the general pattern implies that reaction times are negatively associated with the N2 amplitude and positively with the N2 latency. Previous literature on interference control, however, offers evidence both in support of these results (Huster et al., 2014; Overbye et al., 2020; Rueda et al., 2004; Yeung et al., 2004) and against them (Iannaccone et al., 2015; Yeung et al., 2004).

4.2.2. Resource availability and cognitive load

The posterior P3 amplitude showed modulation with respect to the Stroop task, while no difference was observed between the congruent and incongruent trials. Although the P3 component is generally accepted to index stimulus evaluation and decision-making (Kok, 2001; Regan, 1989) it is not uncommon that congruent and incongruent trials do not evoke differential responses with respect to the P3 amplitude in either the classic Stroop task, here the ink-naming task, or the reversed Stroop task, here the word-reading (Atkinson et al., 2003; Kousaie & Phillips, 2012). This notion is also supported by our data. Additionally, our data support the finding that greater amplitudes are observed in the classic Stroop task compared to the reversed Stroop, although some experimental variation of the tasks applied in the comparative study must be considered (Atkinson et al., 2003). Given the behavioral difference in the speed of responding to congruent and incongruent stimuli in both classic and reversed Stroop tasks, the lack of neurodynamic marker distinctively signaling the perceptual conflict and stimulus evaluation implies that both congruent and incongruent stimuli are processed in relatively the same way until the motor output stage. Our data is, therefore, in support of the response competition theory, stating that interference is produced upon the convergence of possible responses at the output stage (Morton & Chambers, 1973).

On the other hand, the P3 amplitude recorded while performing a cognitive-motor dual-task (treadmill) walking has repeatedly been shown to diminish if compared to less complex motor conditions, such as sitting or standing (De Sanctis et al., 2014; De Vos et al., 2014; Reiser et al., 2020; Reiser et al., 2019; Shaw et al., 2018). Here we observed a trend of diminished amplitude in standing and walking compared to sitting, however only at a significant Alpha level of 0.1 following the Bonferroni correction. Our data show the trend that increases in demand for postural control result in decreased P3 amplitude, which could indicate that the same resource pool was used by the overlapping neural sources involved in cognitive and motor control (Bradford et al., 2019; Gramann et al., 2010; Gwin et al., 2011; Makeig et al., 2004; Polich, 2007) resulting in fewer cognitive resources available while engaged in such a dual-task as compared to seated cognitive task execution. Similarly, Theta activity showed reduced power while dual-task walking compared to sitting and standing but only for the word-reading and ink-naming Stroop tasks. The observed effects on Theta power are in line with that of Reiser et al., (2020), which were attributed to the reduction of attentional resources resulting from increased motor task demand.

Furthermore, Alpha power also showed modulation with respect to movement complexity in that it demonstrated less desynchronization, i. e. higher power, during walking compared to sitting and standing. If the Alpha activity can be understood as the complementary effect to the one observed in the Theta range (Mölle et al., 2002), less desynchronization observed during walking might confirm the limited resources suggestion. On the contrary, it has been shown that greater Alpha desynchronization is evoked in response to increasing visual and vestibular complexities in the VR environment (Ehinger et al., 2014) as well as in response to increased optic flow while treadmill walking (Malcolm et al., 2018).

Several studies investigating cognitive-motor dual-tasking interpret variations in P3 amplitudes with the spare capacity theory framework, however, this interpretation might be ambiguous. Namely, the P3 amplitude generally increases with increasing stimulus relevance and decreases when the task becomes more difficult (Kok, 2001), whereas the capacity concept itself implies that more capacity is invested in both cases (Verleger, 2020). Recently, Verleger (2020) presented a less ambiguous concept for interpreting the P3 amplitude in terms of stimulus-response link reactivations.

4.2.3. Conflict resolution and response selection

The LPC which is thought to reflect conflict resolution and response selection processes (Coderre et al., 2011; Donohue et al., 2016; Heidlmayr et al., 2015; Larson et al., 2009; West, 2003) was in our study modulated with respect to the Stroop tasks and motor conditions. In response to the switching task, the LPC was greater 500–700 ms after the stimulus presentation compared to the less challenging Stroop tasks, however, no effects of the congruity were noted in our data. Literature typically reports greater amplitude of the LPC evoked in response to the incongruent as opposed to the congruent stimuli (Hanslmayr et al., 2008; Markela-Lerenc et al., 2004; West et al., 2005), and in a 4-choice response sets compared to the 2-choice set. This suggests that rather than congruity, the LPC amplitude is determined by the relative task difficulty and the amount of attention required. In the present study, the task difficulty was not manipulated by increasing the number of possible responses but by increasing the number of task sets while keeping the number of response options constant. It was not the congruity of the stimuli in any of the Stroop tasks that distinguished LPC responses, but rather the general difficulty of the Stroop task itself. Despite some ambiguity, the cognitive processes underlying this component can be in one way or the other related to conflict processing.

The LPC was also greater in sitting and standing conditions compared to walking during 500–600 ms post-stimulus across all Stroop tasks. To our knowledge, this is the first study investigating and demonstrating motor-related modulation of the LPC. If the LPC was sensitive to the task difficulty and the required attentional demands of a task at hand, it should not be surprising that the cognitive control for maintaining gait would reflect and modulate LPC too. The cognitive-motor system controls posture which must be dynamically maintained throughout the gait cycle (Woollacott & Tang, 1997) and despite environmental perturbations (Perry, 2003). Because attentional control is continuously engaged during walking, we hypothesized that the LPC amplitude will reflect this by an increase in amplitude relative to sitting or standing. However, although cognitive control is required for gait, the gait itself is highly automatized and in a healthy population with ample cognitive reserve might not result in worsened performance during cognitive-motor dual-tasking. What is more, under such low cognitive-motor loads the stabilization of gait together with performance benefits had previously been observed (Decker et al., 2012; Fearon et al., 2021; Hamacher et al., 2019; Verrel et al., 2009). From this perspective, the non-significant trend for diminished Stroop effect which indicates greater Interference control observed during walking in the present study, alongside the observed lower LPC amplitude while walking, might together signal the enhancement of interference control or facilitation of conflict resolution and response selection on a

neurophysiological level.

4.3. Quality of the EEG signal in mobile settings

When considering the analyses presented in the preset paper it should be noted that the quality of the EEG signal was worsened during the mobile conditions compared to static standing and sitting conditions as shown by the higher epoch rejection rates observed in walking (Table S1). Consequently, fewer trials for the mobile conditions were included in the analyses, however, the anticipation of compromised signal quality due to the movement had been taken into account a priori and the trial number had been inflated to survive even a 50% epoch rejection rate. For example, if out of the 72 congruent trials in the word-reading task only 50% survived, we expect that 36 resulting trials would nonetheless give a reasonable quality of the averaged ERP. In simulated within-subject experiments, Boudewyn et al. (2018) showed that for stable ERP components, such as the error-related negativity (ERN), increasing the number of trials from 8 to 16 while using small effects and a small number of participants more than doubled statistical power while increasing the number of participants had a smaller impact. They also show the opposite was true for the between-subject designs. Given the fact we investigated the most typical interference control-related ERP components using a within-subject design, we expect that the observed effects typically showing medium-to-large effect sizes are sufficiently powered due to a high volume of trials and despite a relatively low number of participants.

4.4. Limitations and future directives

The present study has some limitations that should be considered. First, participants belonged to a broad adult age range, and given the functional and structural brain changes occurring across the life span that support cognitive function (Voelcker-Rehage & Niemann, 2013), some of the cognitive and neurophysiological effects observed here might have been confounded by the age-related brain changes. Second, despite the sample size being calculated a priori to ensure sufficient statistical power of the observed results, the total number of included participants remained low and poses the possibility of being underpowered (Brysbaert, 2019). The results should therefore be considered with caution and weighted in regard to this notion. Third, the motor performance was not recorded beyond the self-selected walking speed. Despite imposing the initially selected walking speed on all dual-task walking conditions, the parameters such as step length, step width, cadence, and stride time variability might show interfering effects on the motor system upon introducing the cognitive-motor dual-task paradigms (Al-Yahya et al., 2011). The future cognitive-motor dual-task walking studies in the field of interference control should aim to comprehensively disentangle the dual-task costs on both motor and cognitive systems using Mobile Brain/Body Imaging (Gramann et al., 2011; Gramann et al., 2014; Makeig et al., 2009) that allow for synchronized recording and analyses of multimodal data. Fourth, the order of the Stroop tasks was not counterbalanced within a certain motor condition but always followed the same order, namely the word-reading, ink-naming, and switching tasks; the Stroop tasks were ordered from the least challenging to the most challenging. This trade-off sacrificed the implementation of a fully randomized order encompassing cognitive tasks and motor conditions. Given that each Stroop task was repeated three times (once per motor condition) and that motor conditions were counterbalanced across the participants, the systematic bias related to the conditions' order was minimized by also accounting for a carryover effect. The Supplementary Materials (Fig. S3, Table S2, and Table S3) provide graphic depictions and results of statistical tests arguing against the effect of practice. Future research should employ a fully randomized design to rule out the potential effects of task order on neurophysiological markers. Lastly, it should be noted that overground and treadmill walking differ in some kinetic, kinematic,

and electromyographic aspects (Semaan et al., 2022), and as such the results of the present study might not be directly transferable to ecologically more valid overground walking.

5. Conclusion

The present study exposes several aspects of how low-intensity steady-state activity, such as treadmill walking, interacts with and modulates executive function. While early markers signal elevated levels of working memory during walking, the later stages of information processing index favorable outcomes in terms of faster interference suppression and response selection compared to static conditions. Together with the observed trend of the smaller Stroop effect while walking compared to sitting and standing, this study shows how such low-intensity activity might promote performance on selective attention and inhibitory control measures. Conversely, the neural markers show indications of cognitive-motor interference, possibly due to the two modalities tapping into the same resource pool, however without detrimental behavioral effects in healthy participants. Importantly, here we also expose by replicating data from Gajewski et al. (2020) that the frontocentral N2 might not exclusively reflect the degree of conflict of a task at hand, but might instead index the processing of task-irrelevant stimuli as previously suggested (Kousaie & Phillips, 2012). The results of the present study reflect that existing interpretations of ERP components and ERSP measures that were recorded in stationary settings should be considered with care as they might not be directly transferable to freely moving subjects. Future studies are, however, needed to confirm these speculations in different settings, including during overground walking, using other interference control paradigms, such as the flanker task, and on a greater sample size.

Author contributions

MP and UM designed the study protocol, MP and MMŠ collected the data, NO and AM supported data analysis by developing and customizing signal-processing pipeline scripts, MP analyzed the data and prepared the first draft, and the continuous critical revision was performed by KG and UM. All authors read and approved the final version of the manuscript for submission.

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.biopsycho.2023.108543.

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