Physical or cognitive exertion does not influence cortical movement preparation for rapid arm movements

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Motor Control

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Abstract. The contribution of central factors to movement preparation, e.g. the contingent negative variation (CNV), and the influence of fatigue on such factors is still unclear, even though executive cognitive functions are regarded as key elements in motor control. Therefore, this study examined CNV-amplitude with electroencephalography (EEG) in 22 healthy humans during a rapid arm movement task (RAM) prior and following three experimental conditions: 1) a no exertion/control condition, 2) a physical exertion, and 3) a cognitive exertion. CNV-amplitude was not affected by a single bout of physical/cognitive exertion, nor by the control condition. Furthermore, no time-on-task effects of the RAM on the CNV were found. Exertion did not affect cortical movement preparation, which is in contrast to previous findings regarding time-on-task effects of exertion on CNV. Based on the current findings the RAM is deemed suitable to measure cortical movement preparation, without being affected by learning effects, and physical/cognitive exertion.

Key words: electroencephalography; contingent negative variation; exertion; central nerve system

Introduction

Fatigue is a disabling symptom which causes limitations in physical and cognitive function due to interactions between performance fatigability and perceived fatigability (Enoka & Duchateau, 2016; Muller & Apps, 2018). Different types of exertion can induce fatigue (Chaudhuri & Behan, 2004; Muller & Apps, 2018) if they are of sufficient intensity and/or duration that the capacities of an individual are exceeded. For instance, physical exertion of the muscles (PE) causing a diminished responsiveness of muscles to neural excitation and consequently a decreased force production (Bisson, McEwen, Lajoie, & Bilodeau, 2011; Corbeil, Blouin, Begin, Nougier, & Teasdale, 2003), and cognitive exertion (CE) which can induce “a psychobiological state with feelings of subjective tiredness and diminished energy (Boksem & Tops, 2008) that arises when the effort costs for a task begin to outweigh the possible benefits of further continuation of that task” (Van Damme, Becker, & Van der Linden, 2018) have been described. Consequently, a diminished value is appointed to the effortful task at hand, which leads to decreased motivation and reduced task performance (Van Damme et al., 2018). Furthermore, previous research indicated that exerting tasks might have local effects, as well as general or more distant effects which are centrally mediated (Strang, Berg, & Hieronymus, 2009). However, evidence for such central processes is scarce.

Limited cognitive function is characterized by disturbed attention, action monitoring and cognitive control processes (Boksem & Tops, 2008; van der Linden, Frese, & Meijman, 2003). The contribution of cognitive function to motor performance and the effect of fatigue on this process should be considered (Abd-Elfattah, Abdelazeim, & Elshennawy, 2015) since executive cognitive functions are recognized as key factors in locomotor control (Abd-Elfattah et al., 2015). Hence, when these executive cognitive functions are affected by fatigue, alterations in motor performance can occur as a result. In this connection, fatigue is hypothesized to affect movement preparation as it is associated with decreased cognitive and/or motor task performance, e.g. slower reaction times and diminished task accuracy (Boksem, Meijman, & Lorist, 2006; Mackworth, 1964; Marcora, Staiano, & Manning, 2009; Tanaka, Ishii, & Watanabe, 2014).

Movement preparation is an important part of the motor control system, which plays a paramount role for attaining and retaining optimal balance and postural control (Hodges & Moseley, 2003). In this regard, movement preparation patterns of the trunk muscles prior to peripheral movements, for instance rapid arm movements (RAM) (Allison & Henry, 2002; Strang & Berg, 2007; Strang et al., 2009; Strang, Choi, & Berg, 2008) have been examined extensively. During such tasks postural control is challenged by internal perturbation forces, and optimal preparatory activation of the trunk muscles occurring prior to movement initiation is needed to anticipate and neutralize these forces. Altered (usually delayed) preparatory trunk muscle activation during such perturbation tasks is often observed in people with low back pain (Knox, Chipchase, Schabrun, Romero, & Marshall, 2018; Suehiro, Ishida, Kobara, Osaka, & Watanabe, 2018) and is considered to contribute to the recurrence or persistence of pain complaints (Apkarian, Hashmi, & Baliki, 2011; Moseley & Flor, 2012). Therefore, such tasks as the RAM are mainly used to examine the motor control of individuals by assessing the posture controlling trunk muscle activity rather than the activity of the prime mover muscles which initiate the internal perturbation (e.g. Deltoid muscle with RAM). However, the contribution of central factors to motor control and the influence of exertion of the trunk muscles on these factors is less examined. Hence, in this study such a RAM task will be performed to assess a central indicator of movement preparation, i.e. the contingent negative variation (CNV). This is a negative-going slow-wave brain potential which is measured by electroencephalography (EEG) (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). The CNV consists of an early and late phase (Connor & Lang, 1969), and arises between one cue warning the participant for a movement to come, and another imperative go cue that signals the initiation of this movement (Walter et al., 1964). The early CNV, a first small negative deflection in the EEG-signal, is thought to mainly reflect sensory orienting to the warning cue (Kok, 1978). The late CNV, a second negative deflection, starts to arise about one to two seconds before the go cue and reaches its peak at the go cue. It represents a combination of anticipation for the sensory processing of the go cue (Brunia & Damen, 1988; Damen & Brunia, 1987; Gaillard & Van Beijsterveldt, 1991; Rosler, 1991; van Boxtel & Brunia, 1994), and response preparation for the movement to come (van Boxtel & Brunia, 1994). As it is this response preparation or cortical movement preparation that is of main interest for this study, the focus from now on will lie solely on the late CNV.

Regarding PE, acute aerobic exertion was shown not to affect late CNV (Du Rietz et al., 2019; Stroth et al., 2009; Tsai et al., 2014). The influence of isometric trunk muscle exertion on late CNV was not yet studied. However, the 'Bereitschaftspotential' (BP), which also reflects cortical movement preparation (van Boxtel & Brunia, 1994), has been shown to increase following isometric hand grip tasks (Freude & Ullsperger, 1987; Johnston, Rearick, & Slobounov, 2001; Schillings et al., 2006). This increased BP probably reflects enhanced use of attentional resources in order to maintain optimal movement performance despite muscle fatigue, which might diminish performance (Barthel et al., 2001; Freude & Ullsperger, 1987; Johnston et al., 2001; Schillings et al., 2006). Furthermore, other studies also found larger movement-related EEG-potentials in relation to increased perception of effort during physical exertion (de Morree, Klein, & Marcora, 2012, 2014). Hence, one could hypothesize an increase in the late CNV potential as well.

Regarding CE, previous studies have shown that amplitudes of both the late CNV (Boksem et al., 2006) and the lateralized readiness potential (Kato, Endo, & Kizuka, 2009), which reflects later stages of motor programming and activation of response execution

(Masaki, Wild-Wall, Sangals, & Sommer, 2004; Muller-Gethmann, Rinkenauer, Stahl, & Ulrich, 2000), decrease with time-on-task during CE. However, the effects of a single bout of CE on subsequent movement preparation for RAM has not been examined yet.

As the effects of exertion on cortical movement preparation need further clarification, this study will examine and compare the influence of both PE and CE on movement preparation in healthy adult humans. Therefore, the late phase of the CNV potential will be assessed during preparation of RAM and is hypothesized to increase with PE and to decrease with CE.

Materials & methods

Participants

Twenty-two healthy participants between 18 and 45 years old were recruited for this randomized within-subject crossover trial. Participants were recruited between September 2016 and December 2018 using posters, flyers, social media and mouth-to-mouth advertisement in the Dutch-speaking part of Belgium. People with a history of pain or current pain, traumata or severe pathologies, cardiorespiratory, neurological, vestibular, endocrinologic, psychological/psychiatric, cognitive or sleeping disorders, or color blindness, major surgery, clinically relevant malalignments and deformities, or malignancies were excluded from study participation. Professional athletes, pregnant women or women < one year postnatal were also not eligible. Participants were asked to refrain from alcohol, drugs, and analgesics without prescription 24 hours prior to the experiments and to refrain from prescribed medication two weeks prior to the experiments. In addition, participants were asked not to perform extreme physical or mentally exerting activities 48 hours prior to testing.

Procedure

The study protocol was approved by the local ethics committee and all subjects provided signed informed consent before the experiments were initiated.

All participants performed two test sessions with minimally five days in between. Three conditions were examined: a no exertion condition (NE) during the first session, and a CE and PE condition (performed in randomized order) during the second session. During the first session, a general questionnaire regarding medical background, administrative and socio-demographic information was administered. Additionally, before each session, participants completed three standardized questionnaires, i.e. the Profile Of Mood States Short Form (POMS-SF), the International Physical Activity Questionnaire (IPAQ) and the Checklist Individual Strength (CIS). Furthermore, possible confounders such as sleep quality and quantity of the week and night preceding each session were also questioned with visual analogue scales (VAS). Subsequently, to evaluate the CNV, an EEG electrode cap was placed on the participants’ head. In addition, surface electrodes were placed on several abdominal and paraspinal muscles in order to perform electromyography (EMG) of these muscles to examine the effects of exertion on trunk muscle onset timing. These EMG-results have been published elsewhere (Schouppe et al., 2019). During the first session the RAM procedure was explained and practiced in a familiarization session. Participants were given feedback by the researchers regarding optimal arm movement performance and velocity, and regarding abdominal muscle relaxation which was based on the real-time muscle activity displayed in the EMG software. All three conditions were similarly structured: a short instruction phase with 40 practice trials of the RAM, then a first RAM task (RAM1/Pre-exertion) with concurrently EEG measurement, followed by the condition-specific intervention (NE, PE or CE), and concluded with a second RAM task (RAM2/Post-exertion) with concurrent EEG measurement. RAM2 was always performed immediately after performance of the exerting tasks (PE or CE) in order to prevent that participants would already substantially recuperate from the exertion, since fatigue has been shown to have both short and long term effects on task performance (Boucher, Abboud, & Descarreaux, 2012; Carroll, Taylor, & Gandevia, 2017; Peixoto, da Rocha, de Carvalho, & Goncalves, 2010; Wang-Price, Almadan, Stoddard, & Moore, 2017). During the second session a 30-minute rest phase was included between PE and CE conditions. Prior to and following each RAM participants indicated their self-perceived general fatigue on a visual analogue scale (VAS-fatigue). Additionally, ratings of perceived exertion (RPE) of the condition-specific tasks and RAMs were assessed using a Borg scale. An overview of the study protocol is depicted in Figure 1.

Exerting conditions

No Exertion (NE)

To assess possible effects of the mere repetition of the RAM task without exertion in between, a control condition consisting out of 45 minutes relaxed sitting and watching an animated movie was used during the first session.

Physical Exertion (PE)

A combination of a Modified Biering-Sörensen and a Static Abdominal Curl was used during the second session to induce PE of the trunk muscles. Not the arm, but the trunk muscles were exerted, since the latter have a paramount role in postural control and movement preparation in relation to balance perturbations evoked by RAM, as opposed to the prime arm movers of the RAM itself (e.g. Deltoid muscle) which play less of a role in postural control.

During the Modified Biering-Sörensen task participants had to maintain a horizontal prone position of the unsupported upper body as long as possible, while their legs were strapped to a table. This is a validated physical exertion task which has been widely used to assess the endurance capacity of the back extensor muscles (Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008; Stevens et al., 2006).

A Static Abdominal Curl was performed immediately afterwards, to exert the abdominal muscles (Stevens et al., 2006; Van Damme et al., 2014). The unsupported upper body had to be maintained in 45° of trunk flexion, while participants were seated with their legs strapped to a table.

During both tasks participants received standardized motivational cues every 30 seconds. The tasks were discontinued and the endurance times noted when the starting position could no longer be retained, or when participants had to take support or stopped due to pain or discomfort. (Figure 2)

Cognitive Exertion (CE)

A modified incongruent Stroop task analogue to the one described by Pageaux et al. (2015) was used to incite CE during the second session. However, the task duration was extended to 45 minutes in the current study instead of the 30 minutes described by Pageaux et al. (2015), as in the latter study for 25% of participants 30 minutes was insufficient to influence RPE ratings (Pageaux et al., 2015). Participants were positioned in a camera monitored, but isolated room in front of a display. Instructions were provided by the examiner, as well as presented on the display. Participants placed their index and middle fingers of both hands on four key letters with a specific colour (red, green, blue and black). When a word appeared on the screen with the font colour green, blue or black, participants had to push the key letter corresponding to the font of the word, hence this was a font dominant task. However, a word in the color red formed an exception. In this case, the task was word dominant and participants had to push the key letter corresponding to the written word instead of the color (i.e. red) of the word. For example, if the word "black" appeared in a red font, participants had to push the black key letter, as the written word and not the font color was dominant in this case. However, if the word "red" appeared in a black font, they had to push the black key letter, as in this case the font color was dominant. Before the task started, participants were given a short training period until they fully understood the task.

Primary outcome measures

Contingent negative variation (CNV)

EEG was measured using a Biosemi ActiveTwo recording system (BioSemi B.V., The Netherlands) with a sampling rate of 2,048 Hz and 64 active electrodes, placed according to the international 10-20 setting (extended). Bipolar electrodes were placed above and below the left eye and next to the outer left and right canthi to measure eye movements and blinks. A common mode sense active electrode and driven right leg passive electrode were used as online reference (CMS-DRL), and electrode offsets at all electrodes were kept between -50 and 50 µV.

In order to assess CNV as a measure for cortical movement preparation, RAM tasks were performed. This RAM task was first described by Hodges et al. (1997) and is an often-used, valid and reliable task to induce and assess feedforward preparatory activity of the trunk muscles (Marshall & Murphy, 2003). Similar tasks have already been used to assess cortical movement preparation as well (Maeda & Fujiwara, 2007; Tomita, Fujiwara, Mori, & Sakurai, 2012). Participants were positioned in an upright stance with the feet at shoulder width and relaxed arms alongside their body (Park, Tsao, Cresswell, & Hodges, 2014). A first visual stimulus in the form of a white fixation cross (warning cue) appeared on a display two meters in front of the participant at eye-height (Jacobs, Henry, & Nagle, 2010). The appearance of a second direction-specific cue (go cue) in a random interval of 1000-1500ms after the warning cue instructed participants to move their dominant arm (Jacobs, Henry, & Nagle, 2009; Jacobs et al., 2010) as quickly as possible back and forth with an extended elbow. The go cue either existed out of an upwards- or downwards-pointing arrow respectively instructing shoulder anterior flexion up to 90° (Hedayati, Kahrizi, Parnianpour, Bahrami, & Kazemnejad, 2010) or shoulder extension up to 30°. These two arrows were equally often presented in a randomized order. Each movement was followed by a 12s rest period, during which participants were asked to relax the trunk muscles and to continue regular breathing (Jacobs et al., 2009, 2010; Marshall & Murphy, 2008; Marshall, Romero, & Brooks, 2014). The experimental RAM consisted of 40 trials for each movement direction, thus 80 in total, which were presented in a randomized order. Every five minutes a short feedback instruction by the researchers was implemented to ensure optimal movement performance, velocity and relaxation of the abdominal muscles. The continuous EEG-data was synchronized with the performance of the RAM by a central computer which directed the appearance of the visual cues for the RAM, i.e. the warning and go cues, and at the same time sent triggers with the exact time stamp of these events to the EEG-software by use of the trigger cable of the EEG-system.

The EEG-channels were referenced to an average of all electrodes. EEG-signals were filtered with a notch filter (50Hz), and second order zero phase shift Butterworth high- (0.01 Hz) and low-pass (30Hz) filters. Subsequently, the continuous data was segmented into stimulus-locked epochs ranging from 200ms before to 1600ms after the fixation cross. Ocular correction according to the Gratton and Coles technique was performed by use of a vertical (VEOG) and horizontal (HEOG) electrooculographic artifact channel, which were calculated based on the external electrodes applied around the eyes of the participants. After that, a semi-automatic artifact rejection (criteria: lowest activity of 0.5µV allowed, maximal allowed voltage step of 50µV/ms and difference of values of 150µV) was performed in order to remove all remaining ocular movements or other artifacts occurring within the epoch timeframe. Baseline corrections were performed based on a 200ms interval preceding the fixation cross, and a second segmentation was carried out to acquire stimulus-locked epochs ranging from -1000ms to +100ms around the onset of the go cue. These epochs were averaged within each subject for each condition. Finally, grand averages per condition were calculated, as well as a collapsed localizer, which is an average of the waveforms of all participants and all conditions (Luck & Gaspelin, 2017). For the grand averages, at least 30 artifact-free trials were required per condition per subject in order for them to be included in the average. At least 6-12 trials are already considered sufficient to attain a clear CNV potential (Tecce, 1972), but in order to minimize background noise and influence of artifacts most research in this regard applies at least 30 artifact-free trials for CNV calculation (Fujiwara, Tomita, Maeda, & Kunita, 2009; Maeda & Fujiwara, 2007).

Visual inspection of the topography of the collapsed localizer confirmed the central topography of the late CNV described in most CNV literature (Figure 3) (Ansari & Derakshan, 2011; Jacobs et al., 2008; Luck, 2014; Tomita et al., 2012). Therefore, a cluster of the EEG-channels representing clear late CNV activity (large negative activity), i.e. C1, Cz, C2, FC1, FCz, FC2 was made (Luck & Kappenman, 2011). Based on previous literature the timeframe for late CNV analysis was defined as the last 100ms preceding the go cue, as this timeframe is thought to be the most sensitive for preparatory activity prior to rapid arm movements (Fujiwara et al., 2009; Maeda & Fujiwara, 2007; Tomita et al., 2012). Thus, for each of the studied conditions mean area amplitudes of the aforementioned electrode cluster were exported for the last 100ms prior to the go cue for subsequent statistical analysis, as these have been reported to be an unbiased measure of EEG-amplitude (Luck, 2014).

As a secondary analysis, time-on-task effects were also examined. For this purpose, the continuous data of each RAM task was divided into two equal blocks, an early block representing the first half of the RAM (Block 1) and a late block representing the second half of the RAM (Block 2). For each block mean area amplitudes of the late CNV were calculated and averaged per condition over all participants. In this way the effects of time-on-task could be assessed by comparing CNV amplitude of the late blocks with that of the early blocks.

Secondary outcome measures

The *Profile Of Mood State Short Form (POMS-SF)* assessed the participants' mood states by requiring them to rate 32 words in accordance with their self-perceived mood at that moment (Wald & Mellenbergh, 1990). Subscores for affective disturbances regarding depression, anger, fatigue, tension and vigour, and a total score were obtained, with higher scores corresponding to higher mood disturbance. The POMS-SF has been shown to be highly valid, and sufficiently consistent and reliable (de Groot, 1992).

The *International Physical Activity Questionnaire (IPAQ)* indexes the physical activities participants performed during the previous 7 days to estimate their level of physical activity (Booth, 2000; The-IPAQ-group, 1998). The minutes per week spent on work, household, transport, leisure activities, sitting and walking was multiplied by a factor corresponding to the strenuousness of these activities in order to calculate metabolic equivalents (METs). This questionnaire has a decent validity and adequate reliability (Craig et al., 2003; van Poppel, Chin A Paw, & van Mechelen, 2004).

The *Checklist Individual Strength (CIS)* consists of 20 questions about fatigue and behavioral aspects related to fatigue for the previous two weeks (Vercoulen, Alberts, & Bleijenberg, 1999). Subscales regarding subjective fatigue (score range 8-56), concentration (score range 5-35), motivation (score range 4-28) and physical activity (score range 3-21), as well as a total score for general fatigue severity (score range 20-140) were calculated. Higher scores correspond with more fatigue and less concentration, motivation and physical activity. Regarding total fatigue severity low, moderate and high fatigue respectively correspond with scores of <27, 27-35, and >35 (Vercoulen et al., 1999). Excellent validity and reliability were described for the CIS (Vercoulen et al., 1999; Vercoulen et al., 1994).

Ratings on a *visual analogue scale for fatigue (VAS-fatigue)* were administered before and after each RAM. Participants were required to indicate their self-perceived fatigue on a 10 cm continuous horizontal scale ranging from 'no fatigue' to 'highest imaginable fatigue'.

The *ratings of perceived exertion (RPE)* scale assessed the self-perceived exertion caused by the RAMs and condition-specific interventions. Participants had to indicate a score between 6 (no exertion) and 20 (maximal exertion) (Achttien, Staal, & Merry, 2011; Borg, 1998; Borg, 1982).

Statistical analysis

Data were analyzed using IBM SPSS Statistics 25 (IBM Corp., Armonk, N.Y., USA) with the significance level set at 0.05.

A priori sample size calculations based on an articles describing the influence of isometric hand grip muscle exertion on CNV area under the curve resulted in a minimum of 19 participants needed to attain a power of 0.80 with significance level .05 (Schillings et al., 2006). RPE-ratings were compared between conditions with a Friedman test and post-hoc Wilcoxon signed-rank tests with Bonferroni correction.

Baseline descriptives were calculated and the normality of data distribution was assessed with the Shapiro-Wilk test and visual assessment of the scatter plots and histograms. Baseline questionnaire scores were compared between the two test sessions using paired student's t-test in case of normally distributed data or the Wilcoxon matched-pairs signed-ranks test in case of non-normally distributed data.

To answer different research questions several linear mixed model analyses were conducted, for which following factors were defined: *condition* (NE – PE – CE), *task* (RAM 1 – exerting task – RAM 2) with RAM1 and RAM2 respectively representing the RAM performed before and after the exerting task, *time to task* i.e. whether the outcome variable was measured prior to or following the examined task (Pre task – Post task), and *block* (Block 1 – Block 2) with each block representing half of the trials performed during one RAM task, respectively the first and last half of trials. The possible confounding influence of sex, age, IPAQ MET scores, hours of sleep/week, hours of sport/week, VAS sleep quality the night/week before testing, hours of sleep the night before testing, VAS-fatigue ratings, RPE ratings, CIS and POMS subscale and total scores, was examined by evaluating how they affected the model fit. If adding a factor diminished the Akaike's Information Criterion with at least 10 points and/or if it had a significant main effect on the model, it was deemed as a confounder and kept in the analysis to improve the model fit.

Concerning VAS-fatigue, a linear mixed model analysis with VAS-fatigue as the dependent outcome, condition (NE-PE-CE), task (RAM1-exerting task-RAM2) and time to task (Pre-Post task) as the fixed factors, and a random intercept on subject level with a variance components covariance type was carried out.

To examine whether exertion would influence CNV amplitude, a linear mixed model analysis was performed with CNV mean amplitude of the last 100ms before the go cue as the dependent outcome, factors condition (PE-CE) and RAM task (RAM1-RAM2), the CIS-fatigue subscore as a covariate, and a random intercept on subject level with a variance components covariance type. In order to assess whether the repetition of the RAM itself would influence the CNV when NE was induced between two RAMs, an identical analysis was performed, with the exception that only NE as factor condition was used. Furthermore, Cohen's d_{av} effect sizes were calculated for each condition comparing the difference in the estimated means of CNV amplitude from RAM1 to RAM2. Cohen's d_{av} effect sizes can range from very small (0.10), small (0.20), medium (0.50), large (0.80) up to huge (2.0) (Cohen, 1988). Hedges' g correction, using the sample size of the RAM1 measurement as a standardizer (Glass' delta), was applied to these effect size calculations, as this is recommended for studies with small sample sizes.(Lakens, 2013)

To examine time-on-task effects within one RAM performance a mixed model with the CNV mean amplitude of the last 100ms before the go cue as dependent outcome, fixed factors condition (PE-CE), RAM task (RAM1-RAM2) and block (Block 1–Block 2), VAS sleep quality the night before testing as a covariate, and a random intercept on subject level with a variance components covariance type was performed.

Post-hoc comparisons for linear mixed model analyses were performed using Bonferroni corrections.

Results

Confounding influences

The data of 21 participants were analyzed, as one participant fainted during testing and was excluded from data analysis. Baseline characteristics of drop-outs are not described, but were not significantly different from the other participants. The following significant differences were found in baseline measures between sessions 1 (NE) and 2 (CE and PE): higher mean sleep quality, lower CIS-fatigue and lower CIS-total, but higher CIS-motivation scores in session 1 compared to session 2. The only factor that significantly affected the model fit was the CIS-fatigue subscore, which was thus retained as a covariate. Baseline characteristics and between session comparisons of other descriptives are displayed in Table 1 and Table 2**.**

Effects of repetition of the RAM on CNV

The mere repetition of a RAM task (NE condition), which was performed as a control condition, did not alter mean amplitude of the late CNV in the 100ms interval prior to the go cue ($p = .329$). Furthermore, comparing late CNV mean amplitude during the RAM before exertion (RAM 1) between different conditions (NE-PE-CE) also did not show significant differences between repeated RAMs ($p = .649$). Estimated means of the CNV are depicted in Table 3.

Fatigue induction

Median RPE scores regarding the NE, PE and CE interventions were respectively 6.5 (range: 6-12), 16.0 (range: 11-18) and 12.0 (range: 7-16). Thus, the NE did not induce fatigue as expected, while the PE related exertion was considered ‘very high’, and the CE as ‘somewhat high’. This was reflected in a significant between-condition difference in RPE scores for the three condition-specific interventions ($\chi^2(2) = 32.141$, $p < .001$). The NE was experienced as less exerting than both the CE ($Z = -1.139$, $p < .01$) and PE ($Z = -1.861$, $p < .01$) interventions. Between PE and CE, however, no significant differences in RPE scores were eminent ($Z = 0.722$, $p = .91$) (Table 4).

The VAS-fatigue mixed model revealed a significant three-way interaction effect of condition × task × time to task ($F(4;322.011) = 4.666$, $p = .001$). Post-hoc analyses showed that before RAM1 and right before the condition-specific interventions were performed, VAS-fatigue was not significantly different between conditions. Furthermore, VAS-fatigue was not significantly affected by performance of RAM1 (Pre-exertion). Thus, participants had similar fatigue levels before initiation of the testing and before the exerting interventions. Only the PE task performance led to a significant increase in VAS-fatigue ratings immediately following the intervention (p=.044), whereas NE or CE did not significantly affect the VAS-fatigue. VAS-fatigue ratings were also significantly increased after performance of RAM2 (Post-exertion) during NE (p = .026) and PE (p = .049), but not in the CE condition. (Table 5)

Effects of PE and CE on CNV

Neither significant interactions (p = 0.389) nor main effects were found with mixed model analysis regarding the influence of PE or CE on the late CNV in the 100ms interval prior to the go cue during RAM performance. Thus, the PE and CE inducing conditions did not significantly affect late CNV, nor did the late CNV following PE and CE differ between conditions. Estimated means of late CNV are displayed in Table 3 and overlay graphs representing the CNV before and after exertion for channel FCz are depicted in Figure 4 and 5.

Effects of time-on-task of the RAM on CNV

The time-on-task of the RAM did not affect mean amplitude of the late CNV. In a linear mixed model analysis no significant interactions or main effects were found for any of the fixed factors, i.e. condition (PE-CE, p = .456), RAM task (RAM1-RAM2, p = .310), block (Block 1-Block 2, p = .606). Furthermore, effect sizes for differences between blocks were all very low (< 0.08).

Discussion

This study found no effects of a single bout of PE nor CE on the mean amplitude of the late CNV during RAM performance in healthy people. Furthermore, the mere repetition of a RAM did not affect CNV either.

Trunk muscles play an important role in maintaining balance and posture during trunk motor control tasks. Therefore, fatigue of these muscles was thought to impede with maintaining optimal performance of RAMs, which could be reflected by alterations in underlying cortical processes. However, this study found no evidence in line with this hypothesis, as CNV amplitude remained unchanged during such a task. Previous findings concerning the BP potential, however, showed increased BP amplitude after PE (Barthel et al., 2001; Freude & Ullsperger, 1987; Johnston et al., 2001; Schillings et al., 2006). The proposed mechanism behind this increased BP amplitude is that in order to maintain optimal task performance with exerted muscles, people need to address more attentional resources to prepare for subsequent movements (Barthel et al., 2001; Freude & Ullsperger, 1987; Johnston et al., 2001; Schillings et al., 2006). Several methodological differences between the current study and the BP studies might explain why different observations were made for the CNV. Barthel et al. (2001) found decreased BP amplitude after an aerobic exerting task, which rather induces central fatiguing effects than the possibly more peripheral effects of the isometric trunk muscle exertion applied in the current study. In the other BP-studies the PE task and the task for BP assessment were one and the same and fatigue effects were studied by examining the effects of 'time-on-task' on the BP potential (Freude & Ullsperger, 1987; Johnston et al., 2001; Schillings et al., 2006). In the current study, however, the CNV was measured with a task that primarily addresses arm muscles as prime movers, and which has an indirect effect on the exerted trunk muscles through their function of posture preservation. Thus, even though trunk muscles play a key role in optimal RAM performance as prime posture controlling muscles, it is hypothesized that PE effects might be more task specific with cortical movement preparation for a task only being altered when the prime movers for that task are exerted. In line with a systematic review which indicated that non-localized muscle fatigue, i.e. fatigue effects on rested muscles, is highly variable, but has the most chance of occurring with high intensity, isometric, cyclical and bilateral exertions of large muscle masses (Halperin, Chapman, & Behm, 2015) it can also be hypothesized that the PE of the trunk muscles should be of higher intensity and repeated in order to effectively influence movement preparation for RAM. Furthermore, participants were mainly instructed to focus on optimal task performance of the arm movements (i.e. as fast as possible) and not on optimal posture preservation during these movements. Therefore, they might not have invested additional attentional resources towards subsequent movement preparation after PE, but possibly they rather performed these movements with less optimal posture, as PE is known to diminish postural control (Paillard, 2012). Future research could apply kinematic or center of pressure measurements synchronously with EEG to examine this hypothesis.

In studies examining the effects of acute aerobic exercise, similar results as in the current study were found, i.e. no effects on response preparation, reflected by no alterations in CNV amplitude after either cycling (Du Rietz et al., 2019; Stroth et al., 2009) or running (Tsai et al., 2014). In those studies the exerting intervention was also not task-specific for the task used to assess the CNV. Dichotomization of the participants into groups with high vs. low fitness levels in two studies yielded contradictory results with one study finding no effects on CNV (Stroth et al., 2009), whereas the other study stated that CNV area did increase in the frontal area after aerobic exercise, but only in the high fitness group (Tsai et al., 2014). In the current study, physical fitness was not experimentally examined, but physical activity levels based on the IPAQ-questionnaire did not significantly influence CNV amplitude.

The late CNV amplitude was not altered in response to CE in this study. This is in contrast to a previous study, which found that CNV amplitude diminished with time-on-task during cognitive exerting tasks (Boksem et al., 2006). In the latter study, the reduced CNV amplitude was thought to be mediated through decreased motivation and attention towards task continuation that occurred due to monotonous cognitive tasks (Boksem et al., 2006; Mochizuki, Boe, Marlin, & McIlroy, 2017). The fact that in the current study different tasks were performed to respectively induce CE and measure CNV, and that the latter was not cognitively exerting itself, might explain these different findings. The diminished motivation and attention due to the Stroop task might not have transferred to the rather physical RAM, and thus therefore did not affect cortical preparation for trunk muscle activity.

Manipulation checks showed that both the physical and cognitive tasks successfully induced a subjective experience of fatigue, as both received significantly higher RPE-ratings than the NE. Furthermore, self-report measures of perceived fatigue increased after performance of the CE and PE tasks but not after NE, but this was only significant for the PE. In previous studies almost the same PE (Coorevits et al., 2008; Morris & Allison, 2011) and CE (Pageaux et al., 2015) tasks as used in the current study were shown to be valid for inducing fatigue. Other measures like EMG median frequency analysis during PE (Allison & Henry, 2001; Coorevits et al., 2008; Morris & Allison, 2011; Sparto, Parnianpour, Barria, & Jagadeesh, 1999), or Stroop effect analysis during CE, which were not assessed in the current study, could be of additional value as they provide more objective indications of the induced fatigue. Nonetheless, even such measures do not guarantee full objectivity. For instance, highly motivated people often retain task performance on the Stroop task despite fatigue. For such people, only self-reports are able to indicate the experienced fatigue.

The fact that the level of self-perceived fatigue was not equal for the PE and CE task has to be taken under consideration. We avoided differences between conditions with regards to the time intervals between two RAMs. Therefore the duration of the NE and the CE tasks was fixed at 45 minutes. As the PE was performed until individual exhaustion a fixed time could not be used. Hence, the PE task was initiated after 40 minutes of rest, as previous research described average endurance times for this task between 3-5 minutes on average (Van Damme et al., 2014), and thus the total interval would amount to approximately 45 minutes. As it is the cost-benefit balance of the exertion that determines the fatigue experience (Boksem & Tops, 2008), and the costs of the 45-minute CE task possibly weighed less than a PE until exhaustion, this might explain why the self-perceived fatigue after CE did not increase to a similar extent as after PE and did not reach significance.

Another important consideration is that to some extent short-term recovery of the exertion already might have arisen during the post-exertion measurements (Boucher et al., 2012; Carroll et al., 2017; Peixoto et al., 2010), even though the RAM2 was always performed immediately after the exerting task (PE or CE) in order to prevent this. However, previous research showed that long-term effects of fatigue often last beyond 15-30 minutes or even up to several hours after the exerting task (Boucher et al., 2012; Carroll et al., 2017; Peixoto et al., 2010; Wang-Price et al., 2017). This research mainly concerns recovery from physical exertions as research on recovery from cognitive exertions is scarce.

Additional analyses were performed for two purposes. First, it had to be assessed whether the mere repetition of the RAM itself, without exertion, had an influence on cortical movement preparation. The analysis of the NE condition and the comparison of RAM1 between conditions revealed no such effects, and indicated that the CNV remained stable between subsequent repetition blocks. This was achieved by implementing practice trials before the experimental phase, which already optimized the learning process or other improvements in movement preparation due to repetition of the RAM. Second, in the scope of the current study a time-on-task design would have been unfit to separate CE and PE effects during the RAM. Nevertheless, a secondary analysis on the data of the current study was performed to assess time-on-task effects over the course of each RAM task, as time-on-task effects have been frequently used as an outcome measure of fatigue in previous literature. No time-on-task effects were found when comparing CNV amplitudes of early with later trials of the RAM in this study. It has to be considered that only two blocks (early vs. late trials) were studied for this analysis, but, as the division of the EEG-data into two blocks for this analysis already substantially lowered the power, division of data into more and smaller blocks was deemed unreliable. In previous studies time-on-task effects on the BP amplitude were described to be dependent on the task intensity, i.e. heavily exerting isometric tasks (>70% of maximal voluntary contraction) led to a decrease in BP amplitude (Freude & Ullsperger, 1987; Johnston et al., 2001; Schillings et al., 2006), whereas less exerting intensities (50% of maximal voluntary contraction) did not affect BP (Freude & Ullsperger, 1987). Even though the PE task used in the current study was highly exerting, the RAM task itself was of low intensity. Thus, the results of unaltered CNV amplitude with time-on-task of the low-intensity RAM in the current study were in line with the previous BP literature.

As this study found no influences of repetition nor time-on-task of the RAM itself on CNV amplitude, it could be deemed a suitable task to measure cortical movement preparation of gross motor movements in a consistent way, without being affected by learning effects, CE or PE. The current study findings indicate the RAM task can be applied in different settings, both experimental and clinical, without high risk of confounding effects of prolonged task performance on cortical movement preparation. However, this statement only applies to RAM performances lasting up to 20 minutes in healthy, young adults. Furthermore, physical or mental exertions performed before a test protocol should not influence the subsequent RAM assessment. Furthermore, since effect sizes of CNV amplitude differences due to exertion in the current study were trivial to small, no strong conclusions can yet be made and future research with larger samples should be performed.

For future research it would be recommended to examine the CNV after repeated PE of the trunk muscles with high intensity (100% contraction) to further explore non-localized and non-task specific fatigue effects on movement preparation. Furthermore, RAM performance following exerting tasks that highly resemble the RAM task itself, but still are able to distinct between both types of exertion would be interesting as well. For instance, concentric or isometric arm movements for the PE task and a Go-No-go computer task for the CE. While, these type of tasks would target other muscles and cognitive processes than the Biering-Sörensen and the modified incongruent Stroop color-word task, they would allow to examine whether the specificity of the exerting task plays a role in the amplitude of the CNV after exertion.

Conclusion

This study was the first to show that neither a single bout of PE nor CE affected the late CNV amplitude during preparation of rapid arm movements, even though fatigue effects were expected based on previous literature. Cortical preparation for gross motor movement was not influenced by exertion when the properties of the exerting task and the task used to assess CNV were different. Thus, exerting effects might be task-specific in this regard. Future research could examine this further by developing specific PE and CE tasks tailored to the properties of the RAM task. Additionally, as no time-on-task or learning effects of the CNV during RAM performance were found, it is considered an appropriate task to measure cortical movement preparation of gross motor movements in a consistent way.

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Figure captions

Figure 1. Flowchart of the study protocol. *Abbreviations: CE, cognitive exertion; CNV, Contingent Negative Variation; VAS-fatigue, visual analogue scale for fatigue; MVC, maximal voluntary contraction; NE, no exertion; PE, physical exertion; RAM, rapid arm movement task; RPE, rating of perceived exertion*

Figure 2. Physical exerting tasks.

Figure 3. Topography of the collapsed localizer for the late CNV

Figure 4. Grand average response-locked CNV potential for the physical (left plot) and cognitive exertion (right plot) conditions at the FCz electrode. The solid line represents the pre-exertion amplitude, and the dotted line represents the post-exertion amplitude. *Abbreviations: CE, cognitive exertion; PE, physical exertion*

Figure 5. Grand average response-locked CNV potential for the no exertion condition at the FCz electrode. The solid line represents the amplitude during the first rapid arm movement performance, and the dotted line represents the amplitude after the second rapid arm movement performance which was performed after 45 minutes of rest. *Abbreviations: NE, no exertion*

Tables

Table 1. Baseline characteristics (N = 21)

		Mean	SD	N
Age (y)		21,76	1,221	
Gender	**Male**			11
	Female			10
Handedness	**Right**			19
	Left			2
Height (cm)		174,43	8,155	
Weight (kg)		65,90	10,119	
BMI (kg/m²)		21,54	1,984	
Education (y)		15,50	1,378	
Sport (hrs/w)		3,45	2,876	
Sleep (hrs/n)		7,69	0,798	

Abbreviations: hrs/n, hours per night; hrs/w, hours per week; SD, standard deviation.

Table 2. Questionnaire scores

	Session 1		**Session 2**		**Session diff.**
	Mean	SD	Mean	SD	P-value
Mean Sleep Quality (VAS)	6.8	1.30	5.9	1.63	**.020**[†]
Sleep Quality day before session (VAS)	6.8	1.55	6.4	1.49	.357[†]
Hours of sleep/week	7.6	0.88	7.3	0.77	.146[†]
Hours of sleep day before session	7.1	0.75	6.9	1.43	.608[*]
POMS-depression	0.7	1.01	0.6	1.47	.601[†]
POMS-anger	0.8	1.41	1.5	2.75	.056[†]
POMS-tension	2.1	2.09	1.5	2.70	.094[†]
POMS-fatigue	2.1	2.33	2.9	3.46	.228[†]
POMS-vigour	12.3	2.83	10.8	4.56	.134[*]
POMS-total	18.0	5.64	17.3	8.18	.613[†]
CIS-fatigue	20.2	6.67	23.6	9.29	**.011**[*]
CIS-concentration	13.2	5.68	14.8	7.15	.867[†]
CIS-motivation	10.3	3.69	12.1	4.47	**.021**[*]
CIS-activity	8.1	2.63	8.2	2.98	.876[*]
CIS-total	35.6	12.36	42.2	17.75	**.004**[*]
IPAQ-total work	1461.6	3374.68	1250.51	2634.03	.779[†]
IPAQ-total transport	645.1	433.73	815.0	806.20	.841[†]
IPAQ-total domestic & garden	105.8	139.62	248.8	709.20	.955[†]
IPAQ-total leisure	725.7	613.64	774.0	989.14	.619[†]
IPAQ-total walk	718.1	997.35	1068.6	1312.01	.095[†]
IPAQ-total moderate	951.5	1288.61	827.4	849.62	.494[†]
IPAQ-total vigorous	1268.6	3049.52	988.6	1435.50	.919[†]
IPAQ-total physical activity	2938.2	3748.35	3273.5	3246.52	.455[†]
IPAQ-total sitting/week	2567.1	996.96	2594.3	946.96	.911[*]
IPAQ-total sitting/day	366.7	142.42	370.6	135.28	.911[*]

Legend: CIS, Checklist Individual Strength; IPAQ, International Physical Activity Questionnaire; POMS, Profile Of Mood States; SD, Standard Deviation; VAS, visual analogue scale.

[*] *paired student's t-test*
[†] *Wilcoxon matched-pairs signed-ranks test*
***Bold** figures display significance at the p <.05 level.*

Table 3. Estimated means of CNV amplitude

Outcome	**Condition**	**Task**	**EM (µVms)**	**SD (µVms)**	**N**	**95% CI**	**Difference RAM1-2 (µVms)**	**P-value**	**ES**
CNV	NE	RAM 1	-5.2	4.90	20	-7.4,-3.0	1.3	.329	.262
		RAM 2	-3.9	4.66	20	-6.0,-1.8			
	PE	RAM 1	-5.3	4.10	16	-7.4,-3.3	.3	.732	.076
		RAM 2	-5.0	4.31	21	-6.9,-3.1			
	CE	RAM 1	-6.1	4.19	18	-8.1,-4.1	1.5	.115	.342
		RAM 2	-4.6	4.28	20	-6.5,-2.6			

Abbreviations: CE, cognitive exertion; CI, confidence interval; CNV, Contingent Negative Variation amplitude; EM, Estimated Mean;ES, Effect Size (Hedges' g_{av}); N, sample number; NE, no exertion; PE, physical exertion; RAM, rapid arm movement task; SD, standard deviation

Table 4. Median RPE

		Condition					
		NE		PE		CE	
		Median	Range	Median	Range	Median	Range
Time	RAM 1	10,0	12,40	9,5	6,00	10,0	9,00
	Exerting task	6,5	6,00	16,0	7,00	12,0	9,00
	RAM 2	10,0	14,70	10,5	8,00	10,0	10,00

Legend: CE, cognitive exertion; NE, no exertion; PE, physical exertion; RAM, rapid arm movement task; RPE, rating of perceived exertion.

Table 5. Mean VAS-fatigue scores

				Condition					
				NE		PE		CE	
				Mean	SD	Mean	SD	Mean	SD
Task	RAM 1	Time	Pre	2,55	1,367	2,67	1,758	3,12	2,042
			Post	3,25	1,471	3,27	2,018	3,47	2,287
	Exerting task	Time	Pre	3,25	1,471	3,27	2,018	3,47	2,287
			Post	2,55	1,505	4,11	2,102	4,06	2,082
	RAM 2	Time	Pre	2,55	1,505	4,11	2,102	4,06	2,082
			Post	3,49	1,908	3,29	1,795	3,43	2,192

Abbreviations: CE, cognitive exertion; NE, no exertion; PE, physical exertion; RAM, rapid arm movement task; SD, standard deviation; VAS-fatigue, visual analogue scale for fatigue.

Figures

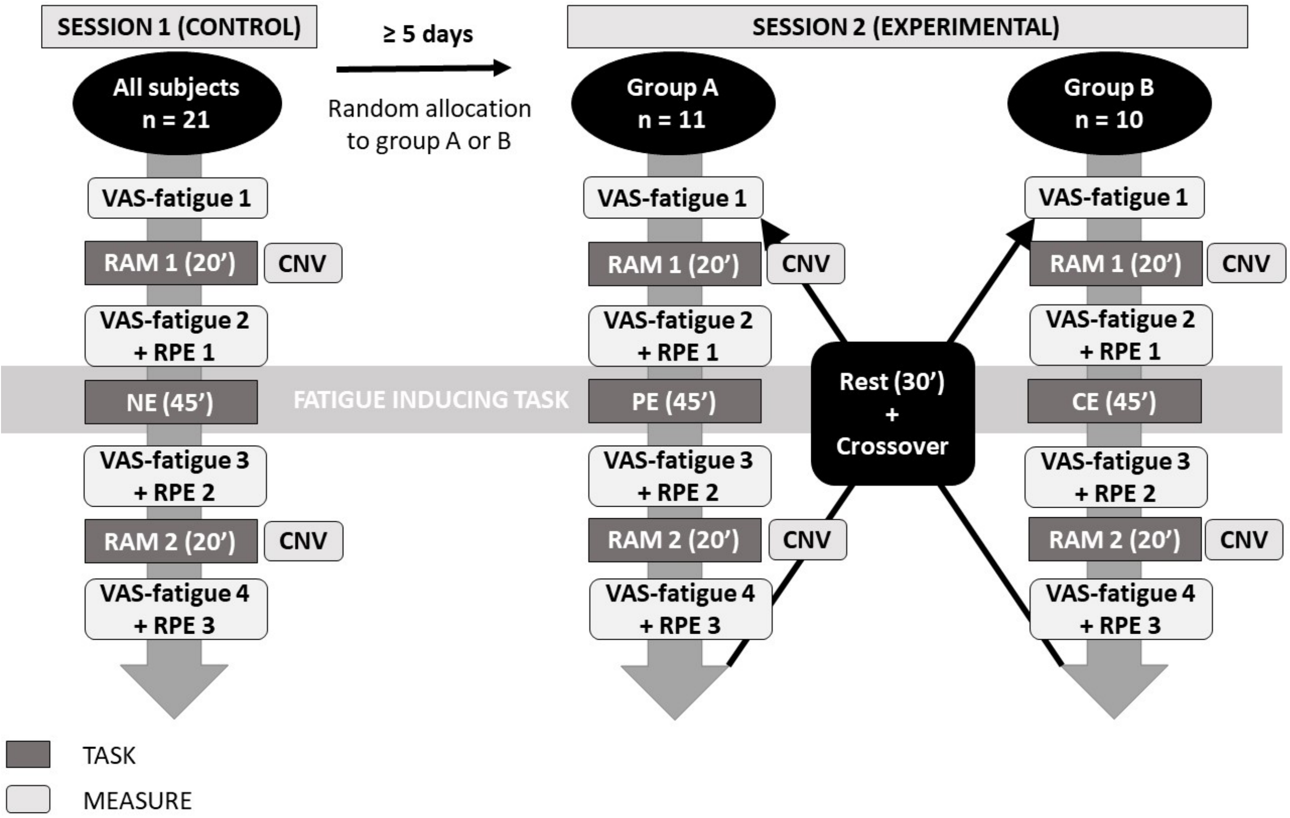


Figure 1.

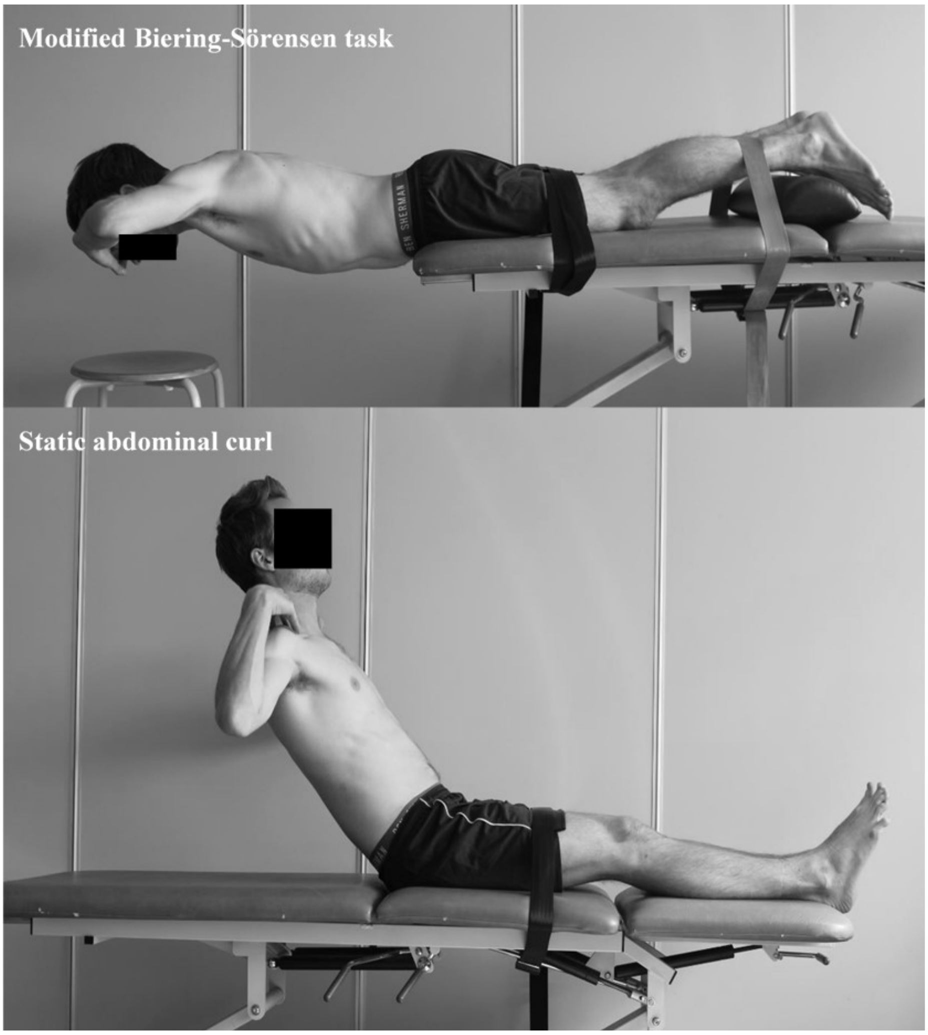
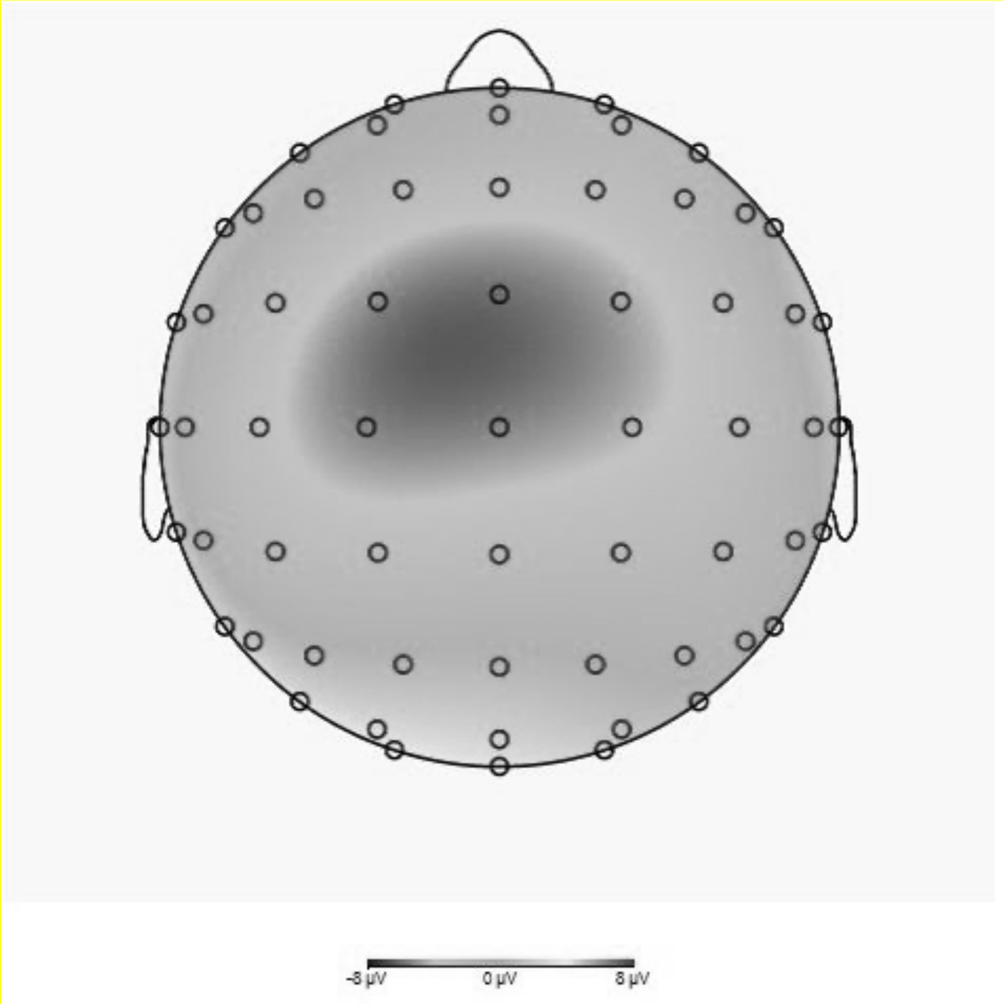


Figure 2.



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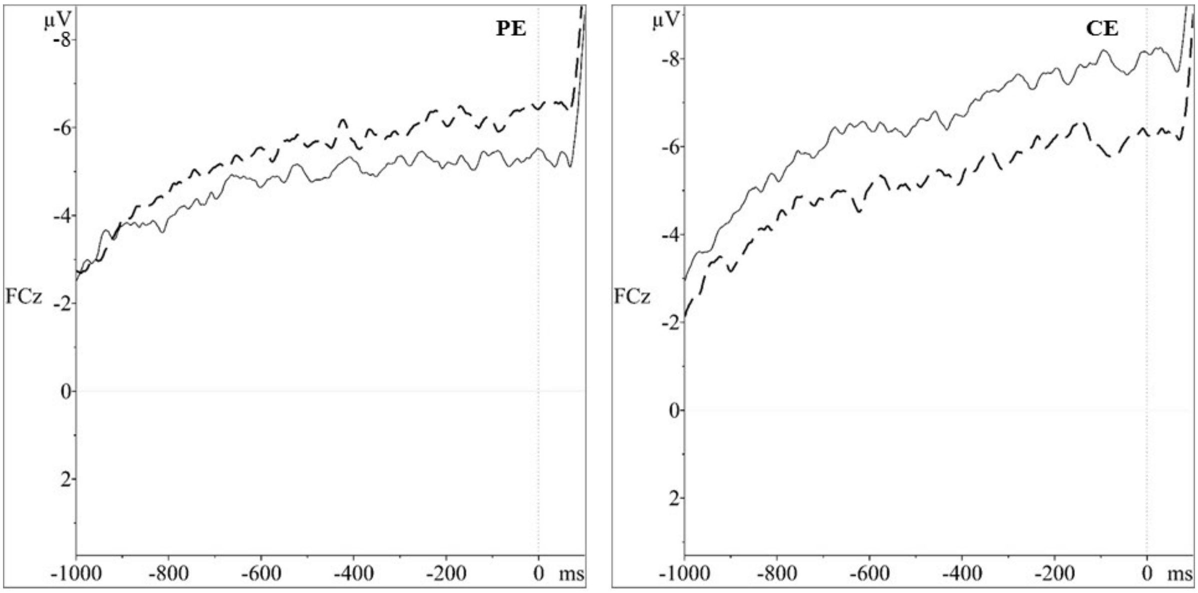
PE
µV
-8
-6
-4
-2
0
2
FCz
-1000
-800
-600
-400
-200
0
ms
CE
µV
-8
-6
-4
-2
0
2
FCz
-1000
-800
-600
-400
-200
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ms

Figure 4.

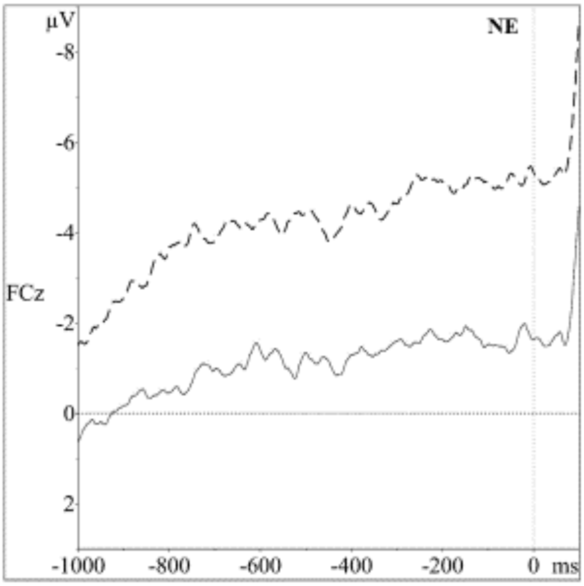

Figure 5.