

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

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4 **Running head:** Exertion does not influence cortical movement preparation.

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6 Motor Control

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

24  
25     **Abstract.** The contribution of central factors to movement preparation, e.g. the contingent  
26     negative variation (CNV), and the influence of fatigue on such factors is still unclear, even  
27     though executive cognitive functions are regarded as key elements in motor control. Therefore,  
28     this study examined CNV-amplitude with electroencephalography (EEG) in 22 healthy humans  
29     during a rapid arm movement task (RAM) prior and following three experimental conditions:  
30     1) a no exertion/control condition, 2) a physical exertion, and 3) a cognitive exertion. CNV-  
31     amplitude was not affected by a single bout of physical/cognitive exertion, nor by the control  
32     condition. Furthermore, no time-on-task effects of the RAM on the CNV were found. Exertion  
33     did not affect cortical movement preparation, which is in contrast to previous findings regarding  
34     time-on-task effects of exertion on CNV. Based on the current findings the RAM is deemed  
35     suitable to measure cortical movement preparation, without being affected by learning effects,  
36     and physical/cognitive exertion.

37  
38     **Key words:** electroencephalography; contingent negative variation; exertion; central nerve  
39     system

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## 40 **Introduction**

41

42 Fatigue is a disabling symptom which causes limitations in physical and cognitive function due  
43 to interactions between performance fatigability and perceived fatigability (Enoka &  
44 Duchateau, 2016; Muller & Apps, 2018). Different types of exertion can induce fatigue  
45 (Chaudhuri & Behan, 2004; Muller & Apps, 2018) if they are of sufficient intensity and/or  
46 duration that the capacities of an individual are exceeded. For instance, physical exertion of the  
47 muscles (PE) causing a diminished responsiveness of muscles to neural excitation and  
48 consequently a decreased force production (Bisson, McEwen, Lajoie, & Bilodeau, 2011;  
49 Corbeil, Blouin, Begin, Nougier, & Teasdale, 2003), and cognitive exertion (CE) which can  
50 induce “a psychobiological state with feelings of subjective tiredness and diminished energy  
51 (Boksem & Tops, 2008) that arises when the effort costs for a task begin to outweigh the  
52 possible benefits of further continuation of that task” (Van Damme, Becker, & Van der Linden,  
53 2018) have been described. Consequently, a diminished value is appointed to the effortful task  
54 at hand, which leads to decreased motivation and reduced task performance (Van Damme et  
55 al., 2018). Furthermore, previous research indicated that exerting tasks might have local effects,  
56 as well as general or more distant effects which are centrally mediated (Strang, Berg, &  
57 Hieronymus, 2009). However, evidence for such central processes is scarce.

58 Limited cognitive function is characterized by disturbed attention, action monitoring  
59 and cognitive control processes (Boksem & Tops, 2008; van der Linden, Frese, & Meijman,  
60 2003). The contribution of cognitive function to motor performance and the effect of fatigue on  
61 this process should be considered (Abd-Elfattah, Abdelazeim, & Elshennawy, 2015) since  
62 executive cognitive functions are recognized as key factors in locomotor control (Abd-Elfattah  
63 et al., 2015). Hence, when these executive cognitive functions are affected by fatigue,  
64 alterations in motor performance can occur as a result. In this connection, fatigue is

65 hypothesized to affect movement preparation as it is associated with decreased cognitive and/or  
66 motor task performance, e.g. slower reaction times and diminished task accuracy (Boksem,  
67 Meijman, & Lorist, 2006; Mackworth, 1964; Marcora, Staiano, & Manning, 2009; Tanaka,  
68 Ishii, & Watanabe, 2014).

69 Movement preparation is an important part of the motor control system, which plays a  
70 paramount role for attaining and retaining optimal balance and postural control (Hodges &  
71 Moseley, 2003). In this regard, movement preparation patterns of the trunk muscles prior to  
72 peripheral movements, for instance rapid arm movements (RAM) (Allison & Henry, 2002;  
73 Strang & Berg, 2007; Strang et al., 2009; Strang, Choi, & Berg, 2008) have been examined  
74 extensively. During such tasks postural control is challenged by internal perturbation forces,  
75 and optimal preparatory activation of the trunk muscles occurring prior to movement initiation  
76 is needed to anticipate and neutralize these forces. Altered (usually delayed) preparatory trunk  
77 muscle activation during such perturbation tasks is often observed in people with low back pain  
78 (Knox, Chipchase, Schabrun, Romero, & Marshall, 2018; Suehiro, Ishida, Kobara, Osaka, &  
79 Watanabe, 2018) and is considered to contribute to the recurrence or persistence of pain  
80 complaints (Apkarian, Hashmi, & Baliki, 2011; Moseley & Flor, 2012). Therefore, such tasks  
81 as the RAM are mainly used to examine the motor control of individuals by assessing the  
82 posture controlling trunk muscle activity rather than the activity of the prime mover muscles  
83 which initiate the internal perturbation (e.g. Deltoid muscle with RAM). However, the  
84 contribution of central factors to motor control and the influence of exertion of the trunk  
85 muscles on these factors is less examined. Hence, in this study such a RAM task will be  
86 performed to assess a central indicator of movement preparation, i.e. the contingent negative  
87 variation (CNV). This is a negative-going slow-wave brain potential which is measured by  
88 electroencephalography (EEG) (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). The  
89 CNV consists of an early and late phase (Connor & Lang, 1969), and arises between one cue

90 warning the participant for a movement to come, and another imperative go cue that signals the  
91 initiation of this movement (Walter et al., 1964). The early CNV, a first small negative  
92 deflection in the EEG-signal, is thought to mainly reflect sensory orienting to the warning cue  
93 (Kok, 1978). The late CNV, a second negative deflection, starts to arise about one to two  
94 seconds before the go cue and reaches its peak at the go cue. It represents a combination of  
95 anticipation for the sensory processing of the go cue (Brunia & Damen, 1988; Damen & Brunia,  
96 1987; Gaillard & Van Beijsterveldt, 1991; Rosler, 1991; van Boxtel & Brunia, 1994), and  
97 response preparation for the movement to come (van Boxtel & Brunia, 1994). As it is this  
98 response preparation or cortical movement preparation that is of main interest for this study,  
99 the focus from now on will lie solely on the late CNV.

100         Regarding PE, acute aerobic exertion was shown not to affect late CNV (Du Rietz et al.,  
101 2019; Stroth et al., 2009; Tsai et al., 2014). The influence of isometric trunk muscle exertion  
102 on late CNV was not yet studied. However, the ‘Bereitschaftspotential’ (BP), which also  
103 reflects cortical movement preparation (van Boxtel & Brunia, 1994), has been shown to  
104 increase following isometric hand grip tasks (Freude & Ullsperger, 1987; Johnston, Rearick, &  
105 Slobounov, 2001; Schillings et al., 2006). This increased BP probably reflects enhanced use of  
106 attentional resources in order to maintain optimal movement performance despite muscle  
107 fatigue, which might diminish performance (Barthel et al., 2001; Freude & Ullsperger, 1987;  
108 Johnston et al., 2001; Schillings et al., 2006). Furthermore, other studies also found larger  
109 movement-related EEG-potentials in relation to increased perception of effort during physical  
110 exertion (de Morree, Klein, & Marcora, 2012, 2014). Hence, one could hypothesize an increase  
111 in the late CNV potential as well.

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

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

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

## 122 **Materials & methods**

123

### 124 *Participants*

125

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

138

### 139 *Procedure*

140

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

143 All participants performed two test sessions with minimally five days in between. Three  
144 conditions were examined: a no exertion condition (NE) during the first session, and a CE and  
145 PE condition (performed in randomized order) during the second session. During the first  
146 session, a general questionnaire regarding medical background, administrative and socio-  
147 demographic information was administered. Additionally, before each session, participants

148 completed three standardized questionnaires, i.e. the Profile Of Mood States Short Form  
149 (POMS-SF), the International Physical Activity Questionnaire (IPAQ) and the Checklist  
150 Individual Strength (CIS). Furthermore, possible confounders such as sleep quality and quantity  
151 of the week and night preceding each session were also questioned with visual analogue scales  
152 (VAS). Subsequently, to evaluate the CNV, an EEG electrode cap was placed on the  
153 participants' head. In addition, surface electrodes were placed on several abdominal and  
154 paraspinal muscles in order to perform electromyography (EMG) of these muscles to examine  
155 the effects of exertion on trunk muscle onset timing. These EMG-results have been published  
156 elsewhere (Schoupe et al., 2019). During the first session the RAM procedure was explained  
157 and practiced in a familiarization session. Participants were given feedback by the researchers  
158 regarding optimal arm movement performance and velocity, and regarding abdominal muscle  
159 relaxation which was based on the real-time muscle activity displayed in the EMG software.  
160 All three conditions were similarly structured: a short instruction phase with 40 practice trials  
161 of the RAM, then a first RAM task (RAM1/Pre-exertion) with concurrently EEG measurement,  
162 followed by the condition-specific intervention (NE, PE or CE), and concluded with a second  
163 RAM task (RAM2/Post-exertion) with concurrent EEG measurement. RAM2 was always  
164 performed immediately after performance of the exerting tasks (PE or CE) in order to prevent  
165 that participants would already substantially recuperate from the exertion, since fatigue has  
166 been shown to have both short and long term effects on task performance (Boucher, Abboud,  
167 & Descarreaux, 2012; Carroll, Taylor, & Gandevia, 2017; Peixoto, da Rocha, de Carvalho, &  
168 Goncalves, 2010; Wang-Price, Almadan, Stoddard, & Moore, 2017). During the second session  
169 a 30-minute rest phase was included between PE and CE conditions. Prior to and following  
170 each RAM participants indicated their self-perceived general fatigue on a visual analogue scale  
171 (VAS-fatigue). Additionally, ratings of perceived exertion (RPE) of the condition-specific tasks



172 and RAMs were assessed using a Borg scale. An overview of the study protocol is depicted in  
173 Figure 1.

174

### 175 *Exerting conditions*

176

#### 177 *No Exertion (NE)*

178

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

182

#### 183 *Physical Exertion (PE)*

184

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

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

195 A Static Abdominal Curl was performed immediately afterwards, to exert the abdominal  
196 muscles (Stevens et al., 2006; Van Damme et al., 2014). The unsupported upper body had to be

197 maintained in 45° of trunk flexion, while participants were seated with their legs strapped to a  
198 table.

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

203

#### 204 *Cognitive Exertion (CE)*

205

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

221 dominant. Before the task started, participants were given a short training period until they fully  
222 understood the task.

223

### 224 *Primary outcome measures*

225

#### 226 *Contingent negative variation (CNV)*

227

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

234 In order to assess CNV as a measure for cortical movement preparation, RAM tasks  
235 were performed. This RAM task was first described by Hodges et al. (1997) and is an often-  
236 used, valid and reliable task to induce and assess feedforward preparatory activity of the trunk  
237 muscles (Marshall & Murphy, 2003). Similar tasks have already been used to assess cortical  
238 movement preparation as well (Maeda & Fujiwara, 2007; Tomita, Fujiwara, Mori, & Sakurai,  
239 2012). Participants were positioned in an upright stance with the feet at shoulder width and  
240 relaxed arms alongside their body (Park, Tsao, Cresswell, & Hodges, 2014). A first visual  
241 stimulus in the form of a white fixation cross (warning cue) appeared on a display two meters  
242 in front of the participant at eye-height (Jacobs, Henry, & Nagle, 2010). The appearance of a  
243 second direction-specific cue (go cue) in a random interval of 1000-1500ms after the warning  
244 cue instructed participants to move their dominant arm (Jacobs, Henry, & Nagle, 2009; Jacobs  
245 et al., 2010) as quickly as possible back and forth with an extended elbow. The go cue either

246 existed out of an upwards- or downwards-pointing arrow respectively instructing shoulder  
247 anterior flexion up to 90° (Hedayati, Kahrizi, Parnianpour, Bahrami, & Kazemnejad, 2010) or  
248 shoulder extension up to 30°. These two arrows were equally often presented in a randomized  
249 order. Each movement was followed by a 12s rest period, during which participants were asked  
250 to relax the trunk muscles and to continue regular breathing (Jacobs et al., 2009, 2010; Marshall  
251 & Murphy, 2008; Marshall, Romero, & Brooks, 2014). The experimental RAM consisted of 40  
252 trials for each movement direction, thus 80 in total, which were presented in a randomized  
253 order. Every five minutes a short feedback instruction by the researchers was implemented to  
254 ensure optimal movement performance, velocity and relaxation of the abdominal muscles. The  
255 continuous EEG-data was synchronized with the performance of the RAM by a central  
256 computer which directed the appearance of the visual cues for the RAM, i.e. the warning and  
257 go cues, and at the same time sent triggers with the exact time stamp of these events to the EEG-  
258 software by use of the trigger cable of the EEG-system.

259         The EEG-channels were referenced to an average of all electrodes. EEG-signals were  
260 filtered with a notch filter (50Hz), and second order zero phase shift Butterworth high- (0.01  
261 Hz) and low-pass (30Hz) filters. Subsequently, the continuous data was segmented into  
262 stimulus-locked epochs ranging from 200ms before to 1600ms after the fixation cross. Ocular  
263 correction according to the Gratton and Coles technique was performed by use of a vertical  
264 (VEOG) and horizontal (HEOG) electrooculographic artifact channel, which were calculated  
265 based on the external electrodes applied around the eyes of the participants. After that, a semi-  
266 automatic artifact rejection (criteria: lowest activity of 0.5 $\mu$ V allowed, maximal allowed voltage  
267 step of 50 $\mu$ V/ms and difference of values of 150 $\mu$ V) was performed in order to remove all  
268 remaining ocular movements or other artifacts occurring within the epoch timeframe. Baseline  
269 corrections were performed based on a 200ms interval preceding the fixation cross, and a  
270 second segmentation was carried out to acquire stimulus-locked epochs ranging from -1000ms

271 to +100ms around the onset of the go cue. These epochs were averaged within each subject for  
272 each condition. Finally, grand averages per condition were calculated, as well as a collapsed  
273 localizer, which is an average of the waveforms of all participants and all conditions (Luck &  
274 Gaspelin, 2017). For the grand averages, at least 30 artifact-free trials were required per  
275 condition per subject in order for them to be included in the average. At least 6-12 trials are  
276 already considered sufficient to attain a clear CNV potential (Tecce, 1972), but in order to  
277 minimize background noise and influence of artifacts most research in this regard applies at  
278 least 30 artifact-free trials for CNV calculation (Fujiwara, Tomita, Maeda, & Kunita, 2009;  
279 Maeda & Fujiwara, 2007).

280 Visual inspection of the topography of the collapsed localizer confirmed the central  
281 topography of the late CNV described in most CNV literature (Figure 3) (Ansari & Derakshan,  
282 2011; Jacobs et al., 2008; Luck, 2014; Tomita et al., 2012). Therefore, a cluster of the EEG-  
283 channels representing clear late CNV activity (large negative activity), i.e. C1, Cz, C2, FC1,  
284 FCz, FC2 was made (Luck & Kappenman, 2011). Based on previous literature the timeframe  
285 for late CNV analysis was defined as the last 100ms preceding the go cue, as this timeframe is  
286 thought to be the most sensitive for preparatory activity prior to rapid arm movements (Fujiwara  
287 et al., 2009; Maeda & Fujiwara, 2007; Tomita et al., 2012). Thus, for each of the studied  
288 conditions mean area amplitudes of the aforementioned electrode cluster were exported for the  
289 last 100ms prior to the go cue for subsequent statistical analysis, as these have been reported to  
290 be an unbiased measure of EEG-amplitude (Luck, 2014).

291 As a secondary analysis, time-on-task effects were also examined. For this purpose, the  
292 continuous data of each RAM task was divided into two equal blocks, an early block  
293 representing the first half of the RAM (Block 1) and a late block representing the second half  
294 of the RAM (Block 2). For each block mean area amplitudes of the late CNV were calculated

295 and averaged per condition over all participants. In this way the effects of time-on-task could  
296 be assessed by comparing CNV amplitude of the late blocks with that of the early blocks.

297

### 298 *Secondary outcome measures*

299

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

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

313 The *Checklist Individual Strength (CIS)* consists of 20 questions about fatigue and  
314 behavioral aspects related to fatigue for the previous two weeks (Vercoulen, Alberts, &  
315 Bleijenberg, 1999). Subscales regarding subjective fatigue (score range 8-56), concentration  
316 (score range 5-35), motivation (score range 4-28) and physical activity (score range 3-21), as  
317 well as a total score for general fatigue severity (score range 20-140) were calculated. Higher  
318 scores correspond with more fatigue and less concentration, motivation and physical activity.  
319 Regarding total fatigue severity low, moderate and high fatigue respectively correspond with

320 scores of <27, 27-35, and >35 (Vercoulen et al., 1999). Excellent validity and reliability were  
321 described for the CIS (Vercoulen et al., 1999; Vercoulen et al., 1994).

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

325 The *ratings of perceived exertion (RPE)* scale assessed the self-perceived exertion  
326 caused by the RAMs and condition-specific interventions. Participants had to indicate a score  
327 between 6 (no exertion) and 20 (maximal exertion) (Achttien, Staal, & Merry, 2011; Borg,  
328 1998; Borg, 1982).

329

### 330 ***Statistical analysis***

331

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

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

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

344 To answer different research questions several linear mixed model analyses were  
345 conducted, for which following factors were defined: *condition* (NE – PE – CE), *task* (RAM 1  
346 – exerting task – RAM 2) with RAM1 and RAM2 respectively representing the RAM  
347 performed before and after the exerting task, *time to task* i.e. whether the outcome variable  
348 was measured prior to or following the examined task (Pre task – Post task), and *block* (Block  
349 1 – Block 2) with each block representing half of the trials performed during one RAM task,  
350 respectively the first and last half of trials. The possible confounding influence of sex, age,  
351 IPAQ MET scores, hours of sleep/week, hours of sport/week, VAS sleep quality the night/week  
352 before testing, hours of sleep the night before testing, VAS-fatigue ratings, RPE ratings, CIS  
353 and POMS subscale and total scores, was examined by evaluating how they affected the model  
354 fit. If adding a factor diminished the Akaike's Information Criterion with at least 10 points  
355 and/or if it had a significant main effect on the model, it was deemed as a confounder and kept  
356 in the analysis to improve the model fit.

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

361 To examine whether exertion would influence CNV amplitude, a linear mixed model  
362 analysis was performed with CNV mean amplitude of the last 100ms before the go cue as the  
363 dependent outcome, factors *condition* (PE-CE) and *RAM task* (RAM1-RAM2), the CIS-fatigue  
364 subscore as a covariate, and a random intercept on subject level with a variance components  
365 covariance type. In order to assess whether the repetition of the RAM itself would influence the  
366 CNV when NE was induced between two RAMs, an identical analysis was performed, with the  
367 exception that only NE as factor *condition* was used. Furthermore, Cohen's  $d_{av}$  effect sizes were  
368 calculated for each condition comparing the difference in the estimated means of CNV



369 amplitude from RAM1 to RAM2. Cohen's  $d_{av}$  effect sizes can range from very small (0.10),  
370 small (0.20), medium (0.50), large (0.80) up to huge (2.0) (Cohen, 1988). Hedges'  $g$  correction,  
371 using the sample size of the RAM1 measurement as a standardizer (Glass' delta), was applied  
372 to these effect size calculations, as this is recommended for studies with small sample  
373 sizes.(Lakens, 2013)

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

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

381

## 382 **Results**

383

### 384 *Confounding influences*

385

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

394

395 *Effects of repetition of the RAM on CNV*

396

397 The mere repetition of a RAM task (NE condition), which was performed as a control condition,  
398 did not alter mean amplitude of the late CNV in the 100ms interval prior to the go cue ( $p =$   
399  $.329$ ). Furthermore, comparing late CNV mean amplitude during the RAM before exertion  
400 (RAM 1) between different conditions (NE-PE-CE) also did not show significant differences  
401 between repeated RAMs ( $p = .649$ ). Estimated means of the CNV are depicted in Table 3.

402

403 *Fatigue induction*

404

405 Median RPE scores regarding the NE, PE and CE interventions were respectively 6.5 (range:  
406 6-12), 16.0 (range: 11-18) and 12.0 (range: 7-16). Thus, the NE did not induce fatigue as  
407 expected, while the PE related exertion was considered ‘very high’, and the CE as ‘somewhat  
408 high’. This was reflected in a significant between-condition difference in RPE scores for the  
409 three condition-specific interventions ( $\chi^2(2) = 32.141, p < .001$ ). The NE was experienced as  
410 less exerting than both the CE ( $Z = -1.139, p < .01$ ) and PE ( $Z = -1.861, p < .01$ ) interventions.  
411 Between PE and CE, however, no significant differences in RPE scores were eminent ( $Z =$   
412  $0.722, p = .91$ ) (Table 4).

413

414 The VAS-fatigue mixed model revealed a significant three-way interaction effect of condition  
415  $\times$  task  $\times$  time to task ( $F(4;322.011) = 4.666, p = .001$ ). Post-hoc analyses showed that before  
416 RAM1 and right before the condition-specific interventions were performed, VAS-fatigue was  
417 not significantly different between conditions. Furthermore, VAS-fatigue was not significantly  
418 affected by performance of RAM1 (Pre-exertion). Thus, participants had similar fatigue levels

419 before initiation of the testing and before the exerting interventions. Only the PE task  
420 performance led to a significant increase in VAS-fatigue ratings immediately following the  
421 intervention ( $p=.044$ ), whereas NE or CE did not significantly affect the VAS-fatigue. VAS-  
422 fatigue ratings were also significantly increased after performance of RAM2 (Post-exertion)  
423 during NE ( $p = .026$ ) and PE ( $p = .049$ ), but not in the CE condition. (Table 5)

424

#### 425 *Effects of PE and CE on CNV*

426

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

433

#### 434 *Effects of time-on-task of the RAM on CNV*

435

436 The time-on-task of the RAM did not affect mean amplitude of the late CNV. In a linear mixed  
437 model analysis no significant interactions or main effects were found for any of the fixed  
438 factors, i.e. condition (PE-CE,  $p = .456$ ), RAM task (RAM1-RAM2,  $p = .310$ ), block (Block 1-  
439 Block 2,  $p = .606$ ). Furthermore, effect sizes for differences between blocks were all very low  
440 ( $< 0.08$ ).

441

#### 442 **Discussion**

443

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

447 Trunk muscles play an important role in maintaining balance and posture during trunk  
448 motor control tasks. Therefore, fatigue of these muscles was thought to impede with  
449 maintaining optimal performance of RAMs, which could be reflected by alterations in  
450 underlying cortical processes. However, this study found no evidence in line with this  
451 hypothesis, as CNV amplitude remained unchanged during such a task. Previous findings  
452 concerning the BP potential, however, showed increased BP amplitude after PE (Barthel et al.,  
453 2001; Freude & Ullsperger, 1987; Johnston et al., 2001; Schillings et al., 2006). The proposed  
454 mechanism behind this increased BP amplitude is that in order to maintain optimal task  
455 performance with exerted muscles, people need to address more attentional resources to prepare  
456 for subsequent movements (Barthel et al., 2001; Freude & Ullsperger, 1987; Johnston et al.,  
457 2001; Schillings et al., 2006). Several methodological differences between the current study  
458 and the BP studies might explain why different observations were made for the CNV. Barthel  
459 et al. (2001) found decreased BP amplitude after an aerobic exerting task, which rather induces  
460 central fatiguing effects than the possibly more peripheral effects of the isometric trunk muscle  
461 exertion applied in the current study. In the other BP-studies the PE task and the task for BP  
462 assessment were one and the same and fatigue effects were studied by examining the effects of  
463 ‘time-on-task’ on the BP potential (Freude & Ullsperger, 1987; Johnston et al., 2001; Schillings  
464 et al., 2006). In the current study, however, the CNV was measured with a task that primarily  
465 addresses arm muscles as prime movers, and which has an indirect effect on the exerted trunk  
466 muscles through their function of posture preservation. Thus, even though trunk muscles play  
467 a key role in optimal RAM performance as prime posture controlling muscles, it is hypothesized  
468 that PE effects might be more task specific with cortical movement preparation for a task only

469 being altered when the prime movers for that task are exerted. In line with a systematic review  
470 which indicated that non-localized muscle fatigue, i.e. fatigue effects on rested muscles, is  
471 highly variable, but has the most chance of occurring with high intensity, isometric, cyclical  
472 and bilateral exertions of large muscle masses (Halperin, Chapman, & Behm, 2015) it can also  
473 be hypothesized that the PE of the trunk muscles should be of higher intensity and repeated in  
474 order to effectively influence movement preparation for RAM. Furthermore, participants were  
475 mainly instructed to focus on optimal task performance of the arm movements (i.e. as fast as  
476 possible) and not on optimal posture preservation during these movements. Therefore, they  
477 might not have invested additional attentional resources towards subsequent movement  
478 preparation after PE, but possibly they rather performed these movements with less optimal  
479 posture, as PE is known to diminish postural control (Paillard, 2012). Future research could  
480 apply kinematic or center of pressure measurements synchronously with EEG to examine this  
481 hypothesis.

482         In studies examining the effects of acute aerobic exercise, similar results as in the current  
483 study were found, i.e. no effects on response preparation, reflected by no alterations in CNV  
484 amplitude after either cycling (Du Rietz et al., 2019; Stroth et al., 2009) or running (Tsai et al.,  
485 2014). In those studies the exerting intervention was also not task-specific for the task used to  
486 assess the CNV. Dichotomization of the participants into groups with high vs. low fitness levels  
487 in two studies yielded contradictory results with one study finding no effects on CNV (Stroth  
488 et al., 2009), whereas the other study stated that CNV area did increase in the frontal area after  
489 aerobic exercise, but only in the high fitness group (Tsai et al., 2014). In the current study,  
490 physical fitness was not experimentally examined, but physical activity levels based on the  
491 IPAQ-questionnaire did not significantly influence CNV amplitude.

492         The late CNV amplitude was not altered in response to CE in this study. This is in  
493 contrast to a previous study, which found that CNV amplitude diminished with time-on-task

494 during cognitive exerting tasks (Boksem et al., 2006). In the latter study, the reduced CNV  
495 amplitude was thought to be mediated through decreased motivation and attention towards task  
496 continuation that occurred due to monotonous cognitive tasks (Boksem et al., 2006; Mochizuki,  
497 Boe, Marlin, & McIlroy, 2017). The fact that in the current study different tasks were performed  
498 to respectively induce CE and measure CNV, and that the latter was not cognitively exerting  
499 itself, might explain these different findings. The diminished motivation and attention due to  
500 the Stroop task might not have transferred to the rather physical RAM, and thus therefore did  
501 not affect cortical preparation for trunk muscle activity.

502         Manipulation checks showed that both the physical and cognitive tasks successfully  
503 induced a subjective experience of fatigue, as both received significantly higher RPE-ratings  
504 than the NE. Furthermore, self-report measures of perceived fatigue increased after  
505 performance of the CE and PE tasks but not after NE, but this was only significant for the PE.  
506 In previous studies almost the same PE (Coorevits et al., 2008; Morris & Allison, 2011) and  
507 CE (Pageaux et al., 2015) tasks as used in the current study were shown to be valid for inducing  
508 fatigue. Other measures like EMG median frequency analysis during PE (Allison & Henry,  
509 2001; Coorevits et al., 2008; Morris & Allison, 2011; Sparto, Parnianpour, Barria, & Jagadeesh,  
510 1999), or Stroop effect analysis during CE, which were not assessed in the current study, could  
511 be of additional value as they provide more objective indications of the induced fatigue.  
512 Nonetheless, even such measures do not guarantee full objectivity. For instance, highly  
513 motivated people often retain task performance on the Stroop task despite fatigue. For such  
514 people, only self-reports are able to indicate the experienced fatigue.

515         The fact that the level of self-perceived fatigue was not equal for the PE and CE task  
516 has to be taken under consideration. We avoided differences between conditions with regards  
517 to the time intervals between two RAMs. Therefore the duration of the NE and the CE tasks  
518 was fixed at 45 minutes. As the PE was performed until individual exhaustion a fixed time

519 could not be used. Hence, the PE task was initiated after 40 minutes of rest, as previous research  
520 described average endurance times for this task between 3-5 minutes on average (Van Damme  
521 et al., 2014), and thus the total interval would amount to approximately 45 minutes. As it is the  
522 cost-benefit balance of the exertion that determines the fatigue experience (Boksem & Tops,  
523 2008), and the costs of the 45-minute CE task possibly weighed less than a PE until exhaustion,  
524 this might explain why the self-perceived fatigue after CE did not increase to a similar extent  
525 as after PE and did not reach significance.

526 Another important consideration is that to some extent short-term recovery of the  
527 exertion already might have arisen during the post-exertion measurements (Boucher et al.,  
528 2012; Carroll et al., 2017; Peixoto et al., 2010), even though the RAM2 was always performed  
529 immediately after the exerting task (PE or CE) in order to prevent this. However, previous  
530 research showed that long-term effects of fatigue often last beyond 15-30 minutes or even up  
531 to several hours after the exerting task (Boucher et al., 2012; Carroll et al., 2017; Peixoto et al.,  
532 2010; Wang-Price et al., 2017). This research mainly concerns recovery from physical exertions  
533 as research on recovery from cognitive exertions is scarce.

534 Additional analyses were performed for two purposes. First, it had to be assessed  
535 whether the mere repetition of the RAM itself, without exertion, had an influence on cortical  
536 movement preparation. The analysis of the NE condition and the comparison of RAM1 between  
537 conditions revealed no such effects, and indicated that the CNV remained stable between  
538 subsequent repetition blocks. This was achieved by implementing practice trials before the  
539 experimental phase, which already optimized the learning process or other improvements in  
540 movement preparation due to repetition of the RAM. Second, in the scope of the current study  
541 a time-on-task design would have been unfit to separate CE and PE effects during the RAM.  
542 Nevertheless, a secondary analysis on the data of the current study was performed to assess  
543 time-on-task effects over the course of each RAM task, as time-on-task effects have been

544 frequently used as an outcome measure of fatigue in previous literature. No time-on-task effects  
545 were found when comparing CNV amplitudes of early with later trials of the RAM in this study.  
546 It has to be considered that only two blocks (early vs. late trials) were studied for this analysis,  
547 but, as the division of the EEG-data into two blocks for this analysis already substantially  
548 lowered the power, division of data into more and smaller blocks was deemed unreliable. In  
549 previous studies time-on-task effects on the BP amplitude were described to be dependent on  
550 the task intensity, i.e. heavily exerting isometric tasks (>70% of maximal voluntary contraction)  
551 led to a decrease in BP amplitude (Freude & Ullsperger, 1987; Johnston et al., 2001; Schillings  
552 et al., 2006), whereas less exerting intensities (50% of maximal voluntary contraction) did not  
553 affect BP (Freude & Ullsperger, 1987). Even though the PE task used in the current study was  
554 highly exerting, the RAM task itself was of low intensity. Thus, the results of unaltered CNV  
555 amplitude with time-on-task of the low-intensity RAM in the current study were in line with  
556 the previous BP literature.

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



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

578

## 579 **Conclusion**

580

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

590

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599

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862 **Figure captions**

863

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

868

869 Figure 2. Physical exerting tasks.

870

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

872

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

877

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

882 **Tables**

883

Table 1. Baseline characteristics (N = 21)

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

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



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*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.*

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Table 3. Estimated means of CNV amplitude

Outcome	Condition	Task	EM ( $\mu$ Vms)	SD ( $\mu$ Vms)	N	95% CI	Difference RAM1-2 ( $\mu$ Vms)	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*

888

Table 4. Median RPE

	Condition					
	NE		PE		CE	
	Median	Range	Median	Range	Median	Range
<b>Time</b> 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.*

889

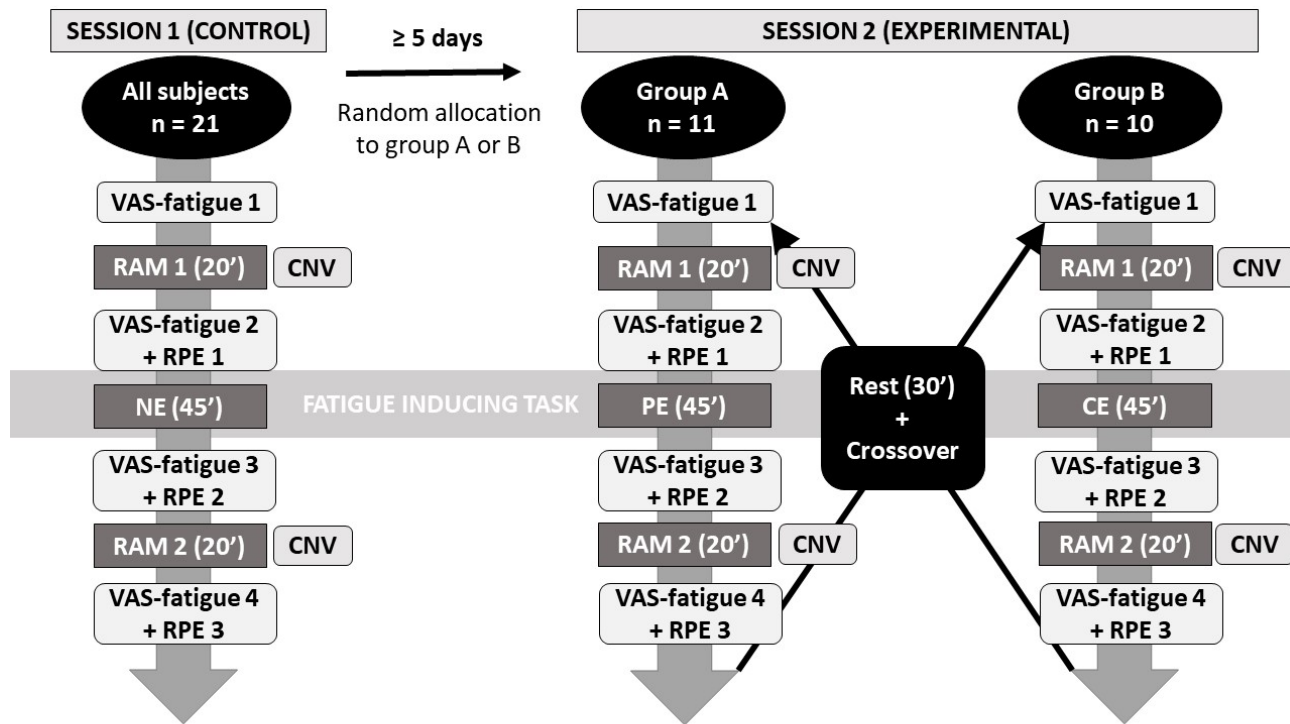
Table 5. Mean VAS-fatigue scores

				<b>Condition</b>					
				NE		PE		CE	
				Mean	SD	Mean	SD	Mean	SD
<b>Task</b>	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.*

891 **Figures**

892

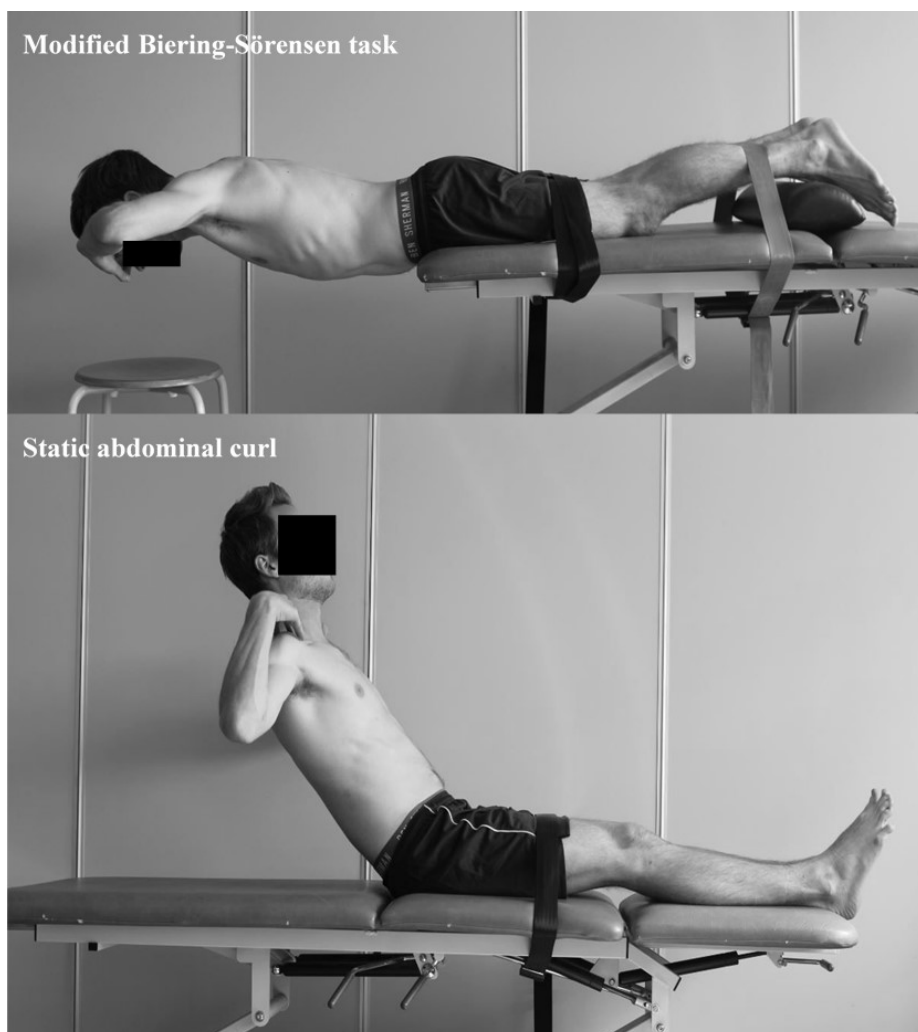


893 ■ TASK  
 893 □ MEASURE

893

894 Figure 1.

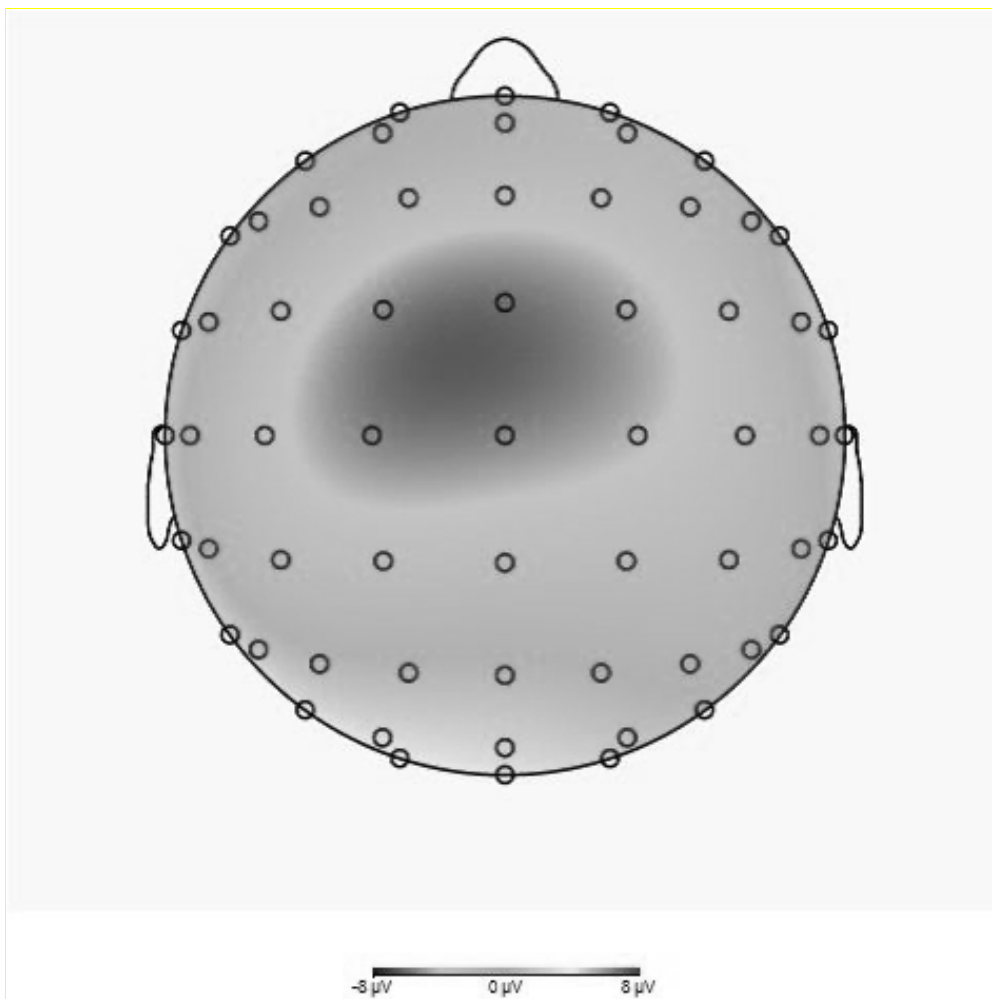
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897 Figure 2.

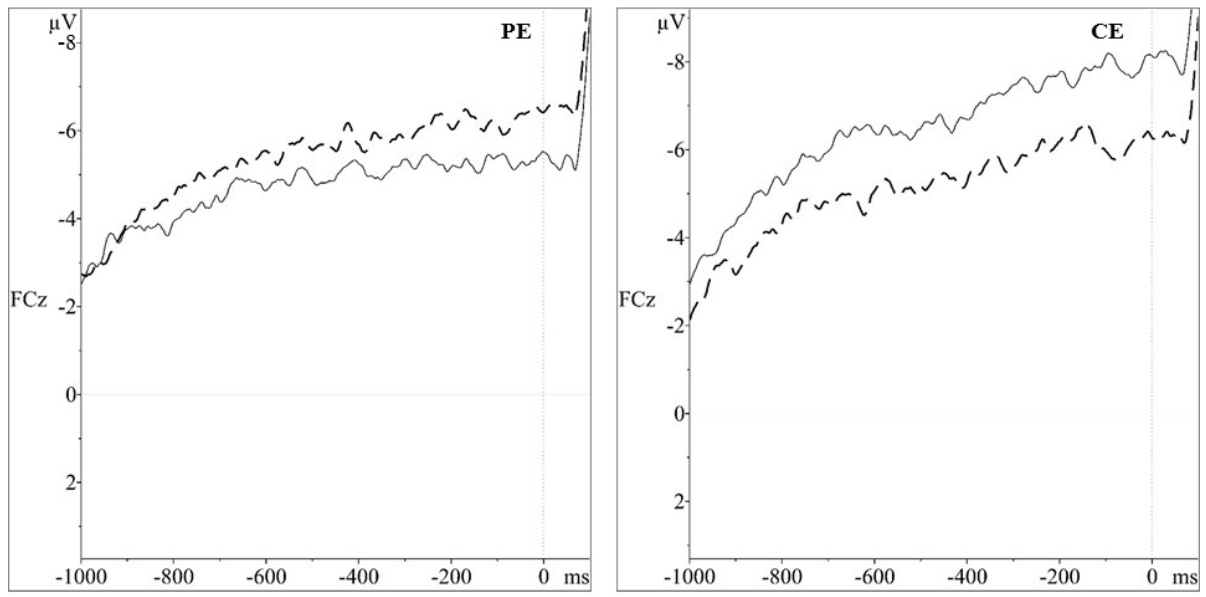
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900 Figure 3.

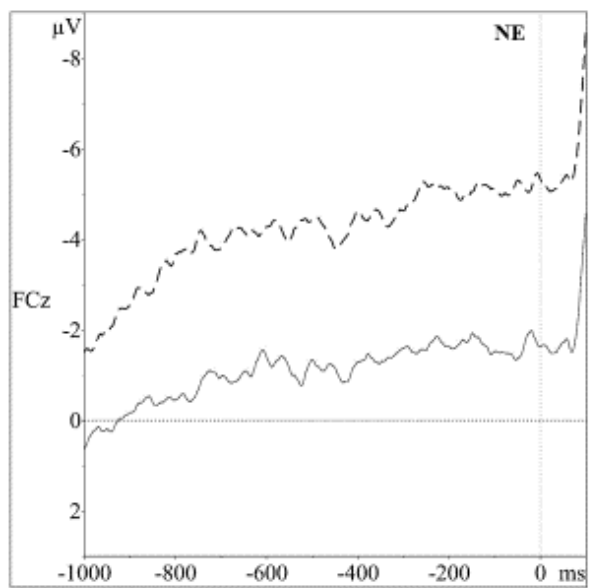
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902

903 Figure 4.





904

905 Figure 5.