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# Slouched and Erect Sitting Postures Affect Upper Limb Maximum Voluntary Force Levels and Fatiguability: A Randomized Experimental Study

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1 **Slouched and erect sitting postures affect upper limb maximum voluntary**  
2 **force levels and fatiguability: a randomized experimental study**

3

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8

9 **Occupational Applications**

10 Modifying the spinal curvature is an empirical approach to treating upper limb  
11 musculoskeletal disorders, often attributed to the balance between physical stress and  
12 individual functional capacities. We completed an experimental biomechanical study to  
13 quantify the effect of seated spinal posture on upper limb functional capacities.  
14 Isometric maximum muscle voluntary forces (MVF) were measured at participants'  
15 shoulder, elbow, and wrist. Fatiguability was also assessed during a repetitive painting  
16 task. Participants were asked to assume both slouched and erect spinal postures, in a  
17 random order. In the erect posture, participants achieved higher shoulder and elbow  
18 isometric MVF levels and took longer to reach a fatigue threshold. Thus, spinal posture  
19 tends to remotely influence upper limb functional capacities, especially at the shoulder  
20 and elbow. Ergonomists should consider spinal posture even when focusing on  
21 musculoskeletal disorders of the upper limb.

22 **Technical Abstract**

23 Background: Musculoskeletal disorders are a major public health issue, and current  
24 treatments often remain unsatisfactory. Treatments based on spinal curvature  
25 modifications are empirically used for upper limb musculoskeletal disorders.

26 Purpose: To determine whether a slouched or erect sitting posture has an effect on upper  
27 limb functional capacities, with tests and outcomes focused on the risk of upper limb  
28 musculoskeletal disorders.

29 Methods: Randomized experimental study, crossover design. Twenty-two right-handed  
30 healthy participants from the local area were assessed in a research laboratory.  
31 Participants' spinal curvatures were increased or decreased, through verbal instructions  
32 and light touch, to place them in a slouched or an erect posture that was stable and  
33 easily maintained, in a random order. Isometric maximum muscle voluntary forces  
34 (MVF) were measured. Participants also performed a repetitive task that simulated  
35 painting, with fatigue level assessed using the CR10 Borg scale. Upper limb  
36 positioning, task setting, and instructions to participants were standardized., and the  
37 investigator was blind to the results of MVF measurements. The main outcomes were  
38 normalized differences in MVF values and time-to-reach "7" on the CR10 scale.

39 Results: There were significantly higher MVF values in the erect posture for the  
40 shoulder and elbow, with respective mean (SD) normalized differences of 11.4 (18.2)  
41 and 11.8 (19.2%); differences approached significance at the wrist [7.7 (18.5)]. The  
42 normalized difference in time-to-reach "7" on the CR10 scale was significantly higher  
43 in the erect posture (by 11.4%).

44 Conclusions: Spinal posture modified individual upper limb functional capacities and  
45 could thus influence the risk of upper limb musculoskeletal disorders.

## 46 **Keywords**

47 upper extremity; spinal curvatures; occupational musculoskeletal disorders; muscle  
48 fatigue; muscle strength

49

## 50 **Introduction**

51 Musculoskeletal disorders (MSDs) are a major public health issue. In 2015, 41% of  
52 European workers reported MSDs in the neck and/or upper-limb over the previous 12 months  
53 (de Kok et al., 2019). MSDs are multifactorial diseases in which psychosocial factors leading  
54 to chronic stress and personal factors such as age, gender, and various health conditions  
55 interact with biomechanical factors. Three biomechanical risk factors are usually highlighted:  
56 forceful exertions, repetitiveness, and awkward joint angles (Bernard et al., 1997; Brière et

57 al., 2015). Current treatments often remain unsatisfactory (Marik & Roll, 2017; Roll &  
58 Hardison, 2017), but treatments based on modifying the spinal curvature (Alcantara, 2006) are  
59 now used by some physiotherapists for shoulder, elbow, and wrist upper limb MSDs without  
60 formal effectiveness proof. This lack of evidence raises the question of whether spinal  
61 curvatures do actually influence the risk of developing upper limb MSDs. We approached this  
62 issue by assessing the influence of spinal curvatures on two biomechanical parameters:  
63 maximum voluntary forces (MVF) and fatiguability. These factors were assumed to be related  
64 to MSD risk factors, particularly to forceful exertions and repetitiveness. They also provided a  
65 measure of upper limb functional capacity.

66 To the best of our knowledge, the effect of spinal curvatures on upper limb  
67 biomechanics has to date only been assessed on the trunk and proximal upper limb. Changes  
68 in spinal curvatures have been shown to modify scapula position (Finley & Lee, 2003;  
69 Kebaetse et al., 1999; Malmström et al., 2015; Miyakoshi et al., 2019; Suzuki et al., 2019),  
70 and conflicting results have been reported regarding humerus axial rotation (Finley & Lee,  
71 2003; Miyakoshi et al., 2019; Suzuki et al., 2019). Spinal posture has also frequently been  
72 reported to impact the electromyographic (EMG) activities of the superficial trunk muscles,  
73 including muscles inserted on the scapula or upper limb (Lee et al., 2016; Malmström et al.,  
74 2015; McLean, 2005; Miyakoshi et al., 2019; Weon et al., 2010). None of these studies  
75 assessed the effect on the most commonly injured shoulder muscles, the rotator cuff muscles  
76 (Kermode et al., 2013; Vandenbushe, 2006). Postural factors might also contribute to the  
77 development of thoracic outlet syndromes (Collins & Orpin, 2021). Little is known, though,  
78 regarding the influence of spinal curvatures on upper limb functional capacity. Kebaetse et al.  
79 (1999) reported that a slouched versus erect sitting posture decreased isometric shoulder  
80 abduction MVF by 16.2%. This finding is of particular interest because shoulder abduction is  
81 also considered to be a posture that increases MSD risk (McAtamney & Nigel Corlett, 1993).

82 Thus, while several upper limb biomechanical parameters have been shown to be influenced  
83 by spinal posture, a knowledge gap remains regarding parameters linked with the risk of  
84 MSDs for the upper limb in its entirety.

85

86 Tasks involving forceful exertions have been proven to increase the risk of upper limb  
87 MSDs (Babski-Reeves & Crumpton-Young, 2003; Bernard et al., 1997; Silverstein et al.,  
88 1987). Two options are available to assess this risk factor according to ergonomics standards  
89 (NF ISO 11228-3, 2007): 1) measuring the percentage of maximum voluntary contraction  
90 (MVC), or 2) assessing fatigue using the CR10 Borg scale. Since the percentage of MVC  
91 depends on both the force requirements for a given task and an individual's functional  
92 capacities, we can assume that the assessment of MVF will reflect a given individual's  
93 sensitivity to exposure to forceful exertion. These MVF measurements are local, analytical  
94 evaluations of an individual's functional capacity. In contrast, physical discomfort self-ratings  
95 reflect overall ability to complete a given task, which may be linked to different kinematics  
96 strategies across time, thereby involving various muscle groups.

97 Although rating scales are based on a self-assessment of exertion through verbal  
98 descriptions linked to numerical levels, there is strong evidence of correlations between these  
99 numerical values and objective variables (Borg, 1982; Meyer, 2014). In the workplace, a value  
100 of "3", or even "2" on the CR10 Borg scale (Borg, 1998) – ranging from "0" to "10" – is  
101 considered the safety limit when performing sustained tasks (Meyer, 2014). For this reason,  
102 low and moderate levels of fatigue are pertinent to the risk of upper limb MSDs. Phan Chan  
103 The and Petiet (2002) reported a lack of reliability for very low CR10 ratings, namely "0.3"  
104 and "0.5", but did not express concern regarding higher ratings, while Meyer (2014) reported  
105 good repeatability for a "moderate" exertion assessment, which corresponds to a "3" CR10  
106 rating. In addition, for repeated trials the CR10 Borg scale is more sensitive and reproducible

107 in detecting slight local muscle fatigue than EMG (Meyer, 2014; Phan Chan The & Petiet,  
108 2002). It can therefore be assumed that an assessment of fatiguability based on the CR10 Borg  
109 scale satisfactorily reflects a given individual's sensitivity to exposure even to a non-maximal  
110 tiring task. This assessment could offer another sound means of quantifying the effect of  
111 spinal posture on the risk of MSDs, which to our knowledge has never previously been  
112 assessed.

113 The objective of this study was to assess the effect of two sitting postures (erect versus  
114 slouched) on two biomechanical risk factors (forceful exertions and repetitiveness), using  
115 MVF measurements and a CR10 scale-based self-assessment of fatigue during an upper limb  
116 non-maximal repetitive tiring task. These measurements were intended to reflect participants'  
117 upper limb functional capacities.

118

## 119 **2. Methods**

120 Twenty-two right-handed healthy participants (14 women, age 23.3 (4.7) years, height  
121 164.7 (5.6) cm, weight 58.7 (4.6) kg and 8 men, age 24.3 (4.2) years, height 172.9 (3.4) cm,  
122 weight 66.3 (5.9) kg) were involved in the study after ethical endorsement from a French  
123 national ethics committee (CPP, N°2020-A00573-36 / SI: 20.05.01.54302). The study took  
124 place at University Gustave Eiffel in Lyon, from October 2020 to January 2021. Participants  
125 were recruited through several websites of Lyon Universities and gave their informed consent.  
126 The sample size was determined for a two-sided paired *t*-test with  $p = 0.05$ , power = 0.8,  
127 effect size = 0.35.

128

129 **2.1. Spinal postures**

130 The posture sequence was randomized into equal-sized groups before the start of the  
131 study by the main investigator, who also enrolled the participants and modified the postures  
132 (crossover design). Eight women and three men started with an erect posture, 6 women and 5  
133 men started with a slouched posture. The participants sat on a seat adjusted to popliteal fossa  
134 height, with their feet placed comfortably on the ground. Their spinal curvatures were  
135 modified using verbal instructions and light touch, placing them in an erect or a slouched  
136 posture. The erect posture was obtained by gently pushing the thoracic apex forward and  
137 simultaneously guiding the medial part of the clavicles upward. For the slouched posture,  
138 participants were instructed to relax so that the pelvis could roll in retroversion and the head  
139 could roll backward. The targeted postures were considered achieved when participants  
140 maintained them with little effort (in other words, when posture-bearing was almost passive)  
141 and when the postures seemed natural to an expert external observer. Moreover, in the  
142 targeted erect posture, small-amplitude lateral head motion seemed easier, giving participants  
143 the feeling that their head was floating above their thorax (Alcantara, 2006). Preliminary tests  
144 on two other participants, using an Xsens Inertial Measurement Unit placed at the T2 vertebra  
145 level, showed that these postures were distinct from each other, with an intra-subject, intra-  
146 session variability that was low relative to the difference in upper back inclination between  
147 postures.

148

149 **2.2. Data collection**

150 MVFs were collected first, from wrist to shoulder. Then the two fatigue tasks were  
151 performed, with a break between them. For MVFs, participants pulled a flat foam-padded  
152 device connected to a 500 N uniaxial load cell (F480TC, TME<sup>®</sup>) by a wire. While positioning  
153 the upper limb for the various measurements (see details below), the investigator was careful

154 to ensure that the natural humerus axial rotation resulting from the spinal posture was  
155 maintained. The padded device was positioned on pre-defined skin marks. The wire length  
156 was adjusted in each posture using a laser pointed at skin markers, once for the wrist and  
157 elbow, and once for the shoulder MVF measurements. The wire was perpendicular to the limb  
158 and the load cell. Participants were asked to maintain their spinal posture and keep their gaze  
159 horizontal. The upper limb and trunk were stabilized manually and by using an armrest (Fig.  
160 1A and 1B) to prevent joint motion after the positioning. The pulling to be performed was  
161 demonstrated to participants and rehearsed before the beginning of the study.

162

163 Figure 1. Material and setting for wrist flexion (A), elbow flexion (B), and shoulder abduction  
164 (C) MVF measurements. Manual stabilization for shoulder and elbow MVF measurements  
165 were identical. Red arrows indicate pulling directions.

166 Beyond assessing specific muscle MVF, the measurements aimed to reflect common  
167 movements that increase MSD risk, namely carrying weight for elbow flexion, and tasks that  
168 involve shoulder anterior elevation. Handling low loads at high frequency is a widespread  
169 workplace risk factor (Brière et al., 2015), and one that can involve a sitting posture (e.g. for  
170 cashiers or among some assembly line tasks). Wrist flexion MVF was measured at 0-20° wrist  
171 flexion, with the elbow flexed 90°, the shoulder at 10° abduction, and the forearm supine (Fig.  
172 1A). Elbow flexion MVF was measured at 90° elbow flexion and 10° shoulder abduction  
173 (Fig. 1B). Shoulder abduction MVF was measured at 90° abduction in the scapula plane,  
174 specifically at 45° shoulder flexion (Fig. 1C).

175 Our goal was to compare MVFs according to posture. As the posture was expected to  
176 influence the investigator's perception of participants' motivation, and hence to influence the  
177 nature and degree of her encouragements, the same verbal encouragements were recorded and  
178 played to participants during each MVF measurement. Participants were provided guidance



179 for a two-second progressive rise, followed by a targeted three-second sustained maximum  
180 contraction. The main investigator was blind to the measurement results. Three trials,  
181 separated by at least a one-minute rest, were performed in each spinal posture for each joint.  
182 The number of MVF trials was reduced to two per posture-articulation for two participants  
183 due to time constraints.

184 We induced upper limb fatigue using a task that involved repeatedly “painting” a  
185 virtual line on a vertical board, at a pace which participants “would choose if they had to paint  
186 a wall all day long” with a paintbrush held like a pencil. The task configuration and setup  
187 were personalized for each participant and posture, using a laser pointer and a ruler (Fig. 2).  
188 In particular, the bottom of the line was placed at glenohumeral-joint height, high enough to  
189 require shoulder-joint angles identified as promoting MSDs (NF ISO 11228-3, 2007).  
190 Participants read the standardized instructions and the description of each level of the CR10  
191 Borg scale, in the French version proposed by Meyer (2014). Then, they performed a  
192 familiarization task with the left arm, followed by a break. During the task, one investigator  
193 asked participants to rate fatigue “at the most affected part of the upper limb” every 15  
194 seconds, in a standardized way (Meyer 2014), and wrote down the answers. The main  
195 investigator only made sure that the task was correctly completed without a significant  
196 posture change and, if necessary, gave verbal reminders. As preliminary tests showed that  
197 high CR10 scores involved a rest time to fully recover from muscle fatigue that was overly  
198 long for our experimental setup, the task was stopped once the score “7” was reached. A rest  
199 time of 5 - 15 minutes had been assessed as sufficient to recover from this fatigue level.

200 Figure 2. Configuration and setup for the fatigue-inducing task.

201

### 202 **2.3. Data processing and analysis**

203 Raw force data were smoothed using a 4<sup>th</sup>-order Butterworth filter with a cutoff  
204 frequency of 1 Hz, using MATLAB software v. 9.8.0 (The MathWorks I, 2021). This cutoff  
205 frequency was chosen as it was visually confirmed remove noise without underestimating  
206 MVF peaks. The maximum value from each set of three trials was considered the MVF. As  
207 MVFs were expected to depend more on individual participants' capacities than on posture,  
208 MVF differences between postures were normalized by their mean for each participant and  
209 joint:  $MVF_n\Delta = (MVF_{\text{erect}} - MVF_{\text{slouched}})/0.5*(MVF_{\text{erect}} + MVF_{\text{slouched}})$ . After visually  
210 confirming data normality, two-sided Student paired *t*-tests were used to assess the effects of  
211 spinal posture on normalized MVF differences. Since we expected MVF values across joints  
212 to be correlated with each other (Bohannon, 1986), we did not perform significance-level  
213 corrections for multiple tests (Bender & Lange, 2001). The outcome of the fatigue-inducing  
214 task was the time-to-reach "7" on the CR10 Borg scale. As the between-posture difference in  
215 time was expected to increase proportionally with time and with individual capacities, this  
216 difference was normalized by the mean time-to-reach "7" for each participant. This approach  
217 ensured that the normalized differences ( $t7n\Delta$ ) had *a priori* the same weight for each  
218 participant. A two-sided Student paired *t*-test was use to compare results between spinal  
219 postures. Finally, to check for persistent fatigue due to the first fatigue task, the effect of  
220 posture sequence (i.e., erect first or slouched first) on the  $t7n\Delta$  value was assessed using linear  
221 models, after visually checking for normal distributions within groups. All statistical analyses  
222 were performed using the R software v. 3.6.1 (R Core Team, 2018). Summary results are  
223 presented as means (SD). The significance level was set at  $p < 0.05$ .

224 A 18'46- (4'02-) minute break separated the two fatigue tasks. The data from one  
225 participant were excluded from all analysis because of failure to understand the instructions:  
226 at the end of the first trial, which was performed in the slouched posture, this participant

227 reported being exhausted, which normally corresponds to “10” on the CR10 scale, while  
228 declaring “7”. Before the second trial started, this participant still reported feeling muscle  
229 fatigue, unlike the other participants.

230

### 231 **3. Results**

#### 232 **3.1. MVF**

233 Isometric MVF values were higher in the erect posture than in the slouched posture for  
234 the shoulder [mean (SD) of normalized differences: 11.4 (18.2)%], the elbow [11.8 (19.2)%],  
235 and the normalized differences approached significance for the wrist [7.7 (18.5)%] (Fig 3).  
236 High interparticipant variability was observed, with higher MVF values in the slouched  
237 posture for approximately one-third of participants.

238

239 Figure 3. Isometric MVF normalized differences between spinal postures. Values are  
240 illustrated for each participant and joint, along with means and 95% confidence intervals of  
241 the means. A positive normalized difference indicates higher MVF in the erect posture.

#### 242 **3.2. Upper limb fatigue**

243 The normalized difference in time-to-reach “7” on the CR10 scale ( $t7n\Delta$  value) was  
244 11.4 (14.5)% higher in the erect posture ( $p < 0.01$ ) than in the slouched one. The posture  
245 sequence effect on the  $t7n\Delta$  value was only of borderline statistical significance ( $p = 0.05$ ),  
246 with lower  $t7n\Delta$  values obtained for the participants whose first randomized posture was  
247 slouched. The time-to-reach “7” on the CR10 scale was 114 (48) seconds (128 (50)seconds  
248 for the erect posture, 101 (42) seconds for the slouched posture).

249

## 250 **4. Discussion**

### 251 ***4.1. Main findings and implications***

252           The objective of this study was to assess the effect of an erect versus a slouched sitting  
253 posture on isometric MVFs and upper limb fatiguability. As hypothesized, posture had an  
254 effect on all these outcomes, except on wrist isometric MVF, for which the effect only  
255 approaches significance. The slouched spinal posture decreased upper limb functional  
256 capacities, even remotely at the elbow. In terms of shoulder abduction and elbow flexion,  
257 spinal posture seems to be a major factor affecting intra-individual variability in isometric  
258 MVF for a given joint angle, along with tiredness and pain, according to a recent literature  
259 review of Cores of Reproducibility in Physiology (Nuzzo et al., 2019). Such changes in upper  
260 limb functional capacities may be a sufficient argument for trying to enhance athletic  
261 performances by modifying the spinal posture. Our findings should also prove applicable to  
262 the workplace, as our tests and outcomes were focused on MSD risk factors. However, the  
263 current study does not formally prove a link between spinal posture and upper limb MSDs:  
264 functional capacities are only intermediate factors in the risk of MSDs. Additional studies are  
265 needed to develop MSD treatments based on spinal posture, and a first step could be to  
266 explore the variability of the spinal posture effect on upper limb functional capacities (see  
267 further discussion below).

268

### 269 ***4.2. Explanatory hypotheses***

270           Induced modifications in upper limb position may explain the effect of spinal postures  
271 on individual functional capacities. A slouched posture increases scapula anterior tilt and  
272 internal rotation and, depending on the upper-limb position, changes scapula upward rotation  
273 and humeral rotation (Finley & Lee, 2003; Kebaetse et al., 1999; Miyakoshi et al., 2019; Suzuki

274 et al., 2019). These modifications might also indirectly affect distal joint angles. Joint angles  
275 are known to modify muscle lever arms and lengths, which could in turn explain an effect on  
276 MVFs (La Delfa et al., 2015; Nuzzo et al., 2019). Interestingly, the results of both MVF  
277 measurements, which were kinematically fully constrained, and fatiguability assessments,  
278 which left participants more freedom in their upper limb kinematics, were affected by spinal  
279 posture. To better understand this finding, the effect of spinal posture on upper limb  
280 kinematics should be further investigated. Finally, complex neural mechanisms might also be  
281 involved, as corticospinal excitability and related motor-evoked potentials are known to be  
282 influenced by upper limb posture (Collins & Button, 2018; Forman et al., 2016).

283

#### 284 ***4.3. Study limitations***

285 Generalizing these MVFs to other settings would be difficult, as the position of the  
286 upper limb bones induced by the spinal posture might interact with the imposed upper limb  
287 positioning. For example, the larger effect of spinal posture on isometric shoulder abduction  
288 MVF found by Kebaetse et al. (1999), which was 16.2% in the erect position compared to  
289 11.4% in our results, might be partly explained by different upper limb positioning, namely  
290 the arm pronation used instead of spontaneous humerus rotation in our study.

291 As the current fatigue-inducing task reflected mainly the risk of shoulder tendinitis  
292 (Bernard et al., 1997; McAtamney & Nigel Corlett, 1993), it probably assessed mainly the  
293 effect of spinal posture on the proximal vs. distal upper limb. Furthermore, the effect of spinal  
294 posture on fatiguability was only investigated at one CR10 level. This “7” CR10 level was  
295 chosen as a compromise between high risk of MSD (Meyer, 2014) and short fatigue-recovery  
296 time. At this “7” level on the scale, the effect of posture sequence on fatiguability was only of  
297 borderline statistical significance. This was unexpected given the shortness of the fatigue task,

298 which was moreover non-maximal and followed by a comfortable recovery time.  
299 Consequently, additional assessments of the effects of spinal posture type and posture  
300 sequence on CR10 ratings were performed (see Appendix). The posture sequence effect was  
301 found to be smaller than the posture type effect, and there appeared to be a mathematical  
302 relationship between CR10 ratings and the effects of posture type and sequence.

303 Another limitation is the high inter-individual variability in posture effect, both for  
304 MVFs and fatigue assessments. Attempts to explain this variability should be made before  
305 undertaking any clinical trial, in order to reduce the risk of adverse effects. Many factors  
306 might be at stake in this variability: the spinal angles reached by each participant in each  
307 posture, participants' usual posture, rigid or flexible spine, postural awareness, ability to deal  
308 with dual-task situations, etc. A closer investigation of the spinal angles related to spinal  
309 postures might shed light on the inter-individual variability; the effect of physical and mental  
310 load associated with postural changes could also be investigated to better understand this  
311 variability, along with comparisons of the effect of passively and actively maintained  
312 postures. Finally, as spinal curvatures are not necessarily identical in the standing and sitting  
313 posture, these results need to be validated in a standing posture, another posture common in  
314 the workplace.

315 In summary, a slouched spinal posture resulted in diminished upper limb functional  
316 capacities, a conclusion already reported for shoulder MVF levels. The present study showed  
317 that spinal posture tends to remotely influence upper limb functional capacities, especially  
318 shoulder and elbow isometric MVF levels and upper limb fatiguability during a repetitive  
319 task. Thus, spinal posture might influence the risk of upper limb MSDs.

320

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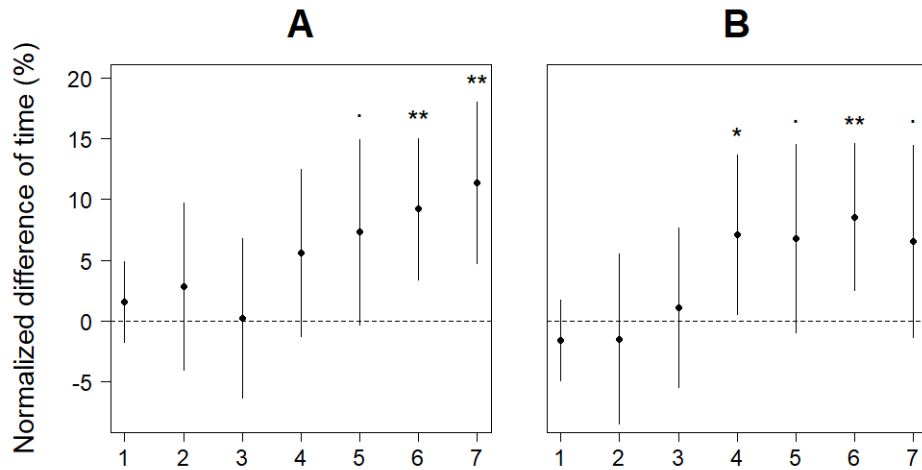
459 **Appendix: Effects of spinal posture type and sequence as a function of CR10 score.**

460

461 The effects of posture type and posture sequence were both assessed for each  
462 consecutive CR10 score. The normalized difference of time-to-reach ( $tn\Delta$ ) each CR10 score  
463 was computed for each participant, as with the assessment of the normalized difference in  
464 time-to-reach “7” on the CR10 scale ( $t7n\Delta$ ). As consecutive  $tn\Delta$  values were expected to be  
465 correlated to each other, we did not perform significance-level correction for multiple tests  
466 (Bender and Lange, 2001). Consecutive  $tn\Delta$  means ( $\mu$ ) were then plotted and modeled by an  
467 approximate function  $\mu = f(V)$ ,  $V$  being the consecutive CR10 score.

468 Regarding posture type (Fig. A1A), there appeared to be a parametric relationship  
469 between CR10 scores and the effect of posture type. Given that “if a dose response is seen, it  
470 is more likely that the association is causal” (Fedak et al., 2015, p. 4), this probable parametric  
471 relationship increases the likelihood of a real impact of posture on fatiguability. The shape of  
472 the curve may suggest different kinds of modeling, depending on the reliability associated  
473 with low CR10 scores. As cited from the literature in the main text, low CR10 scores can be  
474 considered reliable and consequently fit a linear model, once the “3” CR10 rating can be  
475 excluded as an artifact. In this case, the mean normalized time differences ( $\mu$ ) at a given CR10  
476 value ( $V$ ) could be expressed as  $\mu = 0.36 + 1.60 \times V$  ( $r^2 = 0.99$ ). Since  $\mu$  was a normalized  
477 time difference, and not simply a time difference, the slouched sitting posture seemed to  
478 increase fatiguability more quickly as the fatigue level rose, rather than in proportion to the  
479 fatigue level.

480



481

482 Figure A1. Mean normalized differences in time-to-reach the consecutive Borg CR10 score  
 483 and 95% confidence intervals of the means. A) erect – slouched postures. B) first – second  
 484 postures. A positive normalized difference value indicates longer time-to-fatigue for the erect  
 485 position  $**p < 0.01$ ,  $*p < 0.05$ ,  $p < 0.1$ .

486

487 Regarding the sequence of postures (Fig. 1B), consecutive  $\ln\Delta$  displayed a two-step  
 488 curve shape, with a first step of around zero for “1” and “2” CR10 scores and a second step of  
 489 around 7% for “4” to “7” CR10 scores. It was possible to fit a sigmoid curve with exponential  
 490 growth, a.k.a. a Gompertz function (Laird, 1964). Using the R easynls package (Arnhold,  
 491 2017) with a 0.1-step initial constant optimization yielded the following function:  $\mu = 1.54 +$   
 492  $8.87 \exp^{-90042 \exp^{-3.74 V}}$  (adjusted  $r^2 = 0.97$ ). This two-step shape of the curve was puzzling.  
 493 Arguably, the familiarization task may have been sufficient for participants to understand the  
 494 high end of the CR10 scale, while additional tasks might have been needed for them to  
 495 discriminate between low CR10 ratings. Thus, these low ratings may have been  
 496 underestimated during the first task. At the end of the second task, participants may also have  
 497 become less motivated, especially when levels of exertion were high. There may also have  
 498 been a confounding factor; for example, participants’ spines may have been more or less

499 flexible depending on posture sequence. Further, incomplete recovery may have induced  
500 greater fatiguability, but only for high levels of exertion, under the same sustained repetitive  
501 task. As the study was not designed to distinguish between factors leading to a posture  
502 sequence effect, it is impossible to conclude on this point. We can only cite the well-  
503 documented threshold effects during tiring tasks (Seip et al., 1991). Despite the many studies  
504 on this subject and the possibility of persistent fatigue in the shoulder at a CR10 score of “3”  
505 (Meyer, 2014), no overall theoretical model describes recovery in the context of low levels of  
506 fatigue (Scholz et al., 2019), as can be found for the fatigue impact on maximum performance  
507 (Rashedi & Nussbaum, 2015). The current modeling seems to be linear, as a ratio of 1:5  
508 between breaks and working time is recommended (International Organization for  
509 Standardization, 2009). Conflicting results regarding the preventive effect of workplace break  
510 design on MSDs have been reported (Luger et al., 2019; Scholz et al., 2019). Two-step  
511 residual fatigue accumulation might explain such conflicting results, but is beyond the scope  
512 of this study. Nevertheless, we recognize the importance that these results might have for  
513 occupational and sports medicine, where better knowledge regarding low levels of fatigue  
514 after an initial tiring task could be useful in designing workplace breaks and sports training.  
515 That is why we have discussed them in detail in this supplementary material, although further  
516 studies are clearly needed on this issue.

517