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# 1 **Fatigue in elite fencing: effects of a simulated competition**

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35 **ABSTRACT**

36

37 The fatigue induced by fencing remains scarcely investigated. We aimed to investigate both objective  
38 (neuromuscular performance fatigability) and subjective (perceived fatigue, effort and workload)  
39 manifestations of fatigue in elite fencers following a 5-bouts simulated competition. Changes in  
40 countermovement jump height, knee extensors maximal isometric torque, rate of torque development,  
41 voluntary activation, and contractile response to muscular electrical stimulation were measured in 29 elite  
42 fencers [12 epee (6 women), 11 saber (5 women), and 6 foil]. Perceived fatigue and effort were evaluated  
43 with visual analog scales, and the perceived workload with the NASA Task Load Index scale. During the  
44 competition, maximal torque and rate of torque development decreased by 1.6% ( $P=0.017$ ) and 2.4%  
45 ( $P<0.001$ ) per bout, respectively. Perceived fatigue before each bout increased (12% per bout), with similar  
46 values observed at the end of all bouts (bout  $\times$  period interaction:  $P<0.001$ ). Perceived effort increased  
47 during the bouts (10% per period,  $P<0.001$ ) and during the competition (3% per bout,  $P=0.011$ ). Perceived  
48 mental demand increased during the competition (2% per bout,  $P=0.024$ ). These results suggest that elite  
49 fencers needed to increase the allocation of mental rather than physical resources to the task to  
50 counterbalance the deleterious effect of fatigue on performance.

51

52 198 words

53

54

55 **Keywords:** mental fatigue, rate of force development, interpolated twitch technique, combat sport, escrime.

## 56 1. INTRODUCTION

57 Fencing is one of the oldest combat sports and is part of the modern summer Olympic games since its first  
58 edition in 1896. It includes three disciplines, characterized by different weapons: the epee, the foil, and the  
59 saber [for a detailed review, see <sup>1</sup>]. Typically, an international competition of fencing includes preliminary  
60 rounds, or poules, and direct elimination bouts. It lasts more than 9 hours for the finalists, with a net match  
61 time of about 10% (*i.e.*, 17 to 48 minutes in total), with 15 up to 180 minutes of rest between bouts.<sup>1</sup>

62 While the specific rules differ across weapons, the international competitions consist generally of 4-6 bouts  
63 of the poule rounds and ~5 direct elimination bouts. Poule bouts last 3 minutes, where the first athlete  
64 scoring 5 points or with the highest score at the end of the time wins. Once the poule rounds are completed,  
65 fencers are then seeded for the direct elimination bouts based on their performance in the poules. Direct  
66 elimination bouts are fenced to 15 touches where the first athlete scoring 15 points or with the highest score  
67 at the end of the time wins. For the epee and the foil, the bouts are divided into three periods, each one with a  
68 duration of three minutes, with 1 minute breaks between periods. In case of a tie at the end of the third  
69 period, a 1-minute sudden-death bout is used to determine the winner. For the saber, there are two periods  
70 divided by a 1-minute break, which is allowed when either fencer reaches a score of eight. Bouts and periods  
71 are characterized by intense “assaults” followed by a resting time of similar or greater duration [epee: work  
72 to rest ratio = 9s:8s,<sup>2</sup> foil = 5s:15s,<sup>1</sup> saber = 3s:15s.<sup>3</sup>].

73 As other combat sports, fencing practice induces fatigue.<sup>4</sup> Fatigue is a symptom traditionally associated with  
74 increased feelings of tiredness and lack of energy that can be caused by physical, mental or combined  
75 physical and mental exertion.<sup>5,6</sup> Following a task (*e.g.*, a fencing bout), an increase in fatigue could be  
76 identified by objective and subjective manifestations, impairing or not cognitive and physical performance.<sup>6,7</sup>  
77 It is thus important to distinguish fatigue from its objective and subjective manifestations related to a specific  
78 task.

79 The objective manifestation of fatigue in relation to a task can be assessed across various systems of the  
80 human body. For a given absolute work performed, the decrease in performance on the task or of a specific  
81 system is considered a measure of its fatigability.<sup>8</sup> When evaluating fatigability in fencing, previous studies  
82 focused mainly on the changes over time in oxygen consumption or blood lactate concentration, reporting no  
83 change in these variables along the direct elimination phases.<sup>2,9-11</sup> Limited evidence is available on the  
84 performance of the neuromuscular system.<sup>4</sup> Considering the frequent fast displacements of athletes in  
85 fencing, it is of crucial importance to focus on the fatigability of the lower limbs, as previously  
86 suggested.<sup>10,12</sup> A previous study evaluating countermovement jump height (CMJ) observed no change  
87 following a fencing competition.<sup>4</sup> It is worth noting that CMJ does not specifically isolate one muscle group  
88 and includes a coordination aspect, requiring complementary evaluations for a finer monitoring of the lower  
89 limbs' fatigability.<sup>4</sup> Such measures should include the evaluation of maximal force, voluntary activation,  
90 contractile function and the rate of force development, particularly important because of the fast actions  
91 performed in fencing.<sup>13</sup> Subjective manifestations of fatigue refer to the individual report of her/his  
92 experience of fatigue and associated feelings (*i.e.*, tiredness and lack of energy). During a fatiguing task, it is

93 possible to observe changes in the athlete's perception of her/his engagement in a task to perform,<sup>6</sup> namely  
94 the perception of effort.<sup>14-16</sup> Due to the high cognitive and physical demands associated with fencing  
95 competition, fencers have previously reported ratings of perceived effort ranging from "somewhat hard" to  
96 "very hard",<sup>2,4,11</sup> with stable ratings along a competition.<sup>4</sup> However, as the authors monitored the rating of  
97 perceived effort solely after each bout of a competition, it remains unknown how effort perception changes  
98 during a bout.

99 This contraposition observed in the literature between high perceived effort despite no fatigability observed  
100 during a fencing competition deserves further investigation. One possible explanation could be that fencing,  
101 being recognized as a highly technical and tactical discipline,<sup>1,2,17</sup> would be characterized by an intense  
102 mental workload, impacting more the subjective manifestation of fatigue rather than the physiological ones,  
103 which would recover quickly. Also, elite athletes are trained so their physical condition can cope well with  
104 the competition demands, as already suggested.<sup>4</sup> If true, it would be necessary, other than perceived effort, to  
105 better study the characteristics and kinetic of the mental workload of the task along a fencing competition to  
106 provide useful information to coaches and sports scientists.

107 Thus, the present study aimed at investigating the fatigue induced by a simulated competition in elite fencers  
108 of the three weapons: epee, foil, and saber. We evaluated changes in objective and subjective manifestations  
109 of fatigue, measured with changes in i) the knee extensors neuromuscular performance and ii) the  
110 perceptions of fatigue, effort and workload. In line with previous literature demonstrating limited alterations  
111 in neuromuscular function, we hypothesized that a simulated competition would have an important mental  
112 demand, that would be associated with marked subjective manifestations of fatigue and limited fatigability of  
113 the neuromuscular function.

114

## 115 **2. METHODS**

### 116 **2.1 Participants**

117 Twenty-nine elite fencers that were part of the national fencing team in 2022 across the three fencing  
118 weapons were included in the study: 12 from epee (6 women), 11 from saber (5 women), and 6 from foil  
119 (men only). Participants' competition period ranged from November until July. During that period, they  
120 trained on average  $5 \pm 0.5$  days/week and for  $5 \pm 1$  hours/day. The average time dedicated to technical training  
121 was  $3 \pm 1$  hours/day, while the rest consisted of strength and conditioning. All participants gave their written  
122 informed consent before their participation. The study was approved by the ethics committee of Nantes  
123 University (n°08042021).

124

### 125 **2.2 Study design**

126 This study used a within-subject design with the participants tested on two separate sessions, where the  
127 simulated competition took place (the French Institute of Sport center in Paris, and the Federation center in  
128 Nevers). In the first session, the day before the simulated competition, participants were familiarized with all  
129 experimental procedures described thereafter. They also performed a first baseline assessment of the knee

130 extensor neuromuscular function. The knee extensors' neuromuscular function of the lunge leg was  
131 evaluated (*i.e.*, the frontal leg, which corresponds to the side where the athlete held the weapon: right leg  
132  $n=23$ , left leg  $n=6$ ). In the second session, participants completed a simulated fencing competition, with the  
133 neuromuscular function of the knee extensors evaluated before and after the first bout, and after the  
134 competition, as well as self-report of various psychological variables.

135

### 136 2.2.1 Simulated competitions

137 The simulated competition took place between February and May 2022. The competition included 5 bouts of  
138 15 points to simulate the direct elimination stage of an actual international competition. Such competition  
139 format is perceived as more demanding than the 5-points initial bouts, known as “*Poule*”<sup>2,11</sup>. Five simulated  
140 competitions were used to test the different teams involved in the study (epee men and women, saber men  
141 and women, and foil men). Participants used their fencing kit that conforms to the Fédération Internationale  
142 d'Esgrime (FIE) regulations. Official scoring equipment was used and professional referees contributed to  
143 each competition. The opponents in the competition were of similar level. Competitions complied with the  
144 FIE rules, except that a fencer losing a bout was not directly eliminated and kept competing against other  
145 bouts' losers in a parallel competition to ensure that all fencers performed the same number of bouts.  
146 Fencing indoor stadium temperature and humidity were similar across all competitions (22°C, 40% RH).  
147 Two fencing platforms were used, and to ensure that a maximum of two athletes at a time reported to the  
148 neuromuscular testing stand, the bouts on the first platform started 10 to 20 min earlier than the bouts on the  
149 second platform. We ensured that the recovery period between bouts was similar across all athletes. The  
150 result of every bout disputed (victory or defeat) was recorded for each athlete.

151

### 152 2.2.2 Experimental procedures

153 At the beginning of the first session, a standardized warm-up was first performed, consisting of 5 min of  
154 light pedaling on a cycle ergometer and six 5-s knee extensors voluntary isometric contractions (interspersed  
155 by 5 s). Contractions were performed on the isometric dynamometer (ARS dynamometry, SP2, Ltd.,  
156 Ljubljana, Slovenia), starting from a self-selected torque and progressively increasing until the maximal  
157 torque was exerted. Following 1 min of rest, muscle electrical stimulation intensity was determined. Then,  
158 participants were familiarized with the neuromuscular evaluation procedures (see below). At the end of the  
159 session, a full neuromuscular evaluation was performed.

160 On the second session (simulated competition day), participants first underwent a briefing to make sure the  
161 testing protocol was clear and to read the instructions for the self-reported scales and questionnaires. Before  
162 the start of the simulated competition, the athletes were instructed to perform a warm-up identical to what  
163 they routinely do before a world-cup competition. Then, they performed one knee extensor neuromuscular  
164 evaluation. Neuromuscular testing was repeated at the end of the first bout and the end of the last bout.  
165 Maximal torque and CMJ height were also tested after the third bout (see below). Self-reported scales were  
166 administered at each bout.

167

### 168 **2.3 Fatigability of the knee extensor neuromuscular function**

169 The neuromuscular evaluation was designed to include surrogate measures of maximal power (CMJ), force  
170 (maximal isometric contractions) and rapidity (rate of torque development) of the lower limbs. Three CMJs  
171 (with hands placed on the hips) were used to assess jump height, one 5-s maximal voluntary isometric  
172 contractions of the knee-extensors for the assessment of maximal torque, and eight 1-s rapid isometric  
173 contractions to measure rate of torque development.<sup>18</sup> During and 2 s after the maximal isometric  
174 contraction, 100-Hz stimulations were elicited to measure voluntary activation and contractile function.  
175 Contractions were separated by 5-10 s. These tests were chosen based on external consistency, simplicity of  
176 the measure in terms of equipment and execution and proven reliability (e.g.<sup>19-21</sup>).

177 Because sometimes the athletes that participated in the study faced each other, the order of testing  
178 (neuromuscular evaluation or CMJs) was randomized before the end of each bout for the athletes, so that one  
179 athlete performed the CMJs while his/her opponent performed the knee extensors neuromuscular evaluation.  
180 Before the beginning of the competition, participants were equipped with the stimulation electrodes and  
181 cables that were kept under the fencing kit for the first bout. Through pilots, we observed that electrode holds  
182 tend to move or detach from the skin if kept for too many bouts, because of the sweating and attrition with  
183 the pants. Thus, after the first bout, it was decided to remove stimulation electrodes and reapply them before  
184 the last bout. To check the kinetic of eventual neuromuscular impairments during the competition, a maximal  
185 contraction and 3 CMJs were also performed after the third bout. Because of time constraints and athletes'  
186 availability, it was not possible to reapply and remove all electrodes to perform stimulations, nor to perform  
187 the series of rapid contractions after the third bout. At the end of the first, third and fifth bouts, participants  
188 were asked to report to the neuromuscular testing stand immediately after the completion of the scales and  
189 questionnaire. Detailed information on the neuromuscular testing procedures and materials is available in  
190 Appendix A.

191

### 192 **2.4 Subjective measurements**

193 Two visual analog scales were used to measure the perception of fatigue and effort, as well as the NASA  
194 Task-Load-Index (NASA<sub>TLX</sub>) questionnaire for measuring the perceived workload of each bout.<sup>22,23</sup> The  
195 visual analog scale for perceived fatigue was administered immediately before, during the 1-min break  
196 between bouts, and at the end of every bout of the simulated competition. The visual analog scale for  
197 perceived effort was administered during the 1-min break between periods, and the end of every bout of the  
198 simulated competition. The NASA<sub>TLX</sub> was administered at the end of each bout. Participants were instructed  
199 to complete the questionnaires as soon as possible after the end of each phase. To be noted that the NASA<sub>TLX</sub>  
200 also includes an item called "effort", that answers to the question "How hard did you have to work to  
201 accomplish your level of performance?".<sup>22</sup> Detailed information on the testing procedures and materials is  
202 available in Appendix A.

203

## 204 **2.5 Statistical analysis**

205 Statistical analyses were carried out in R statistical environment (V4.2.3, R Foundation for Statistical  
206 Computing, Vienna, Austria).<sup>24</sup> Information on model fitting and assumptions is presented in the Appendix  
207 A. To evaluate the overtime changes of the variables (CMJ, maximal torque, rate of torque development,  
208 voluntary activation, potentiated doublet, NASA<sub>TLX</sub> scores, and visual analog scales), linear mixed-effects  
209 models were fitted to the data using the restricted mean likelihood method in the lme4 package.<sup>25</sup> The  
210 glmmTMB package<sup>26</sup> was used assuming a beta distribution when data could not be modelled with a normal  
211 distribution, due to possible ceiling effect and skewed data density (that was the case for the mental demand  
212 dimension of the NASA<sub>TLX</sub>). P-values were extracted from all F-tests using Satterthwaite's degrees of  
213 freedom method [lmerTest package<sup>27</sup>]. Two different analyses were performed for the physiological  
214 variables: (i) to evaluate the effect of one bout by entering in the model data obtained *pre* and *post* the first  
215 bout of the simulated competition (time encoded as *pre* = 0, *post* = 1) and (ii) to evaluate the evolution of  
216 fatigability over time, all data obtained *post* bouts were used (time encoded as *post first bout* = 0, *post third*  
217 *bout* = 2, *post fifth bout* = 4). For the visual analog scales, only one model was built with the data from all  
218 bouts and periods. Besides the time effect, we also evaluated the effect of weapon, sex, and bout's result  
219 (victory or defeat) for each variable. When a significant main effect or interaction was observed, Tukey post-  
220 hoc correction was applied to pairwise comparisons. For all tests, the significance threshold was set at  
221  $\alpha=0.05$ .

## 222

## 223 **3. RESULTS**

224 Participants' characteristics at baseline for each weapon are presented in table 1. Stimulations were  
225 performed on 24 athletes (6 epee men, 5 epee women, 6 saber men, 2 saber women, and 5 foil), while 5  
226 athletes refused the procedure due to the discomfort caused by the stimulation. For voluntary activation,  
227 because only participants that at the testing session presented values >70% at *pre* were considered, data were  
228 available for 14 participants (2 epee men, 3 epee women, 3 saber men, 2 saber women, 4 foil men). Because  
229 the bout ends when one of the two opponents scores 15 hits, some bouts did not last 3 periods (detailed  
230 information is presented in Appendix B).

231

232 \*\*\*Table 1 about here\*\*\*

### 233

### 234 **3.1 Fatigability of the neuromuscular system**

#### 235

#### 236 *3.1.1 Effect of a single bout*

237 No significant main effects of weapon and bout results were found for the neuromuscular variables (all  
238  $P>0.05$ ). Thus, those effects were removed from the models for the subsequent analyses. CMJ increased  
239 from *pre* to *post*-bout, however, this change was within the standard error of the measure. Men performed  
240 higher jumps heights than women [Intercept (I,  $\beta\pm SE$ ) = 41.4 $\pm$ 1 cm,  $t_{(1,29)}=40.9$ ,  $P<0.001$ ;  $bout_{(0,1)}=1\pm 0.4$  cm,



241  $t_{(1,27)}=2.5$ ,  $P=0.02$ ;  $sex_{(women)}=-10.2\pm 1.6$  cm,  $t_{(1,27)}=-6.3$ ,  $P<0.001$ ]. For maximal torque, two outliers were  
242 detected: The first (saber man) reported an increase from 311 N·m to 367 N·m, and the second (saber  
243 woman) reported a steep drop in maximal torque values (346 N·m to 258 N·m). Maximal torque decreased  
244 from *pre* to *post*, but this change was within the standard error of the measure of the intercept, and it was  
245 greater for men than women [ $I=307.7\pm 16$  N·m,  $t_{(1,26)}=19.2$ ,  $P<0.001$ ;  $bout_{(0,1)}=-10.4\pm 4.7$  N·m,  $t_{(1,25)}=-2.2$ ,  
246  $P=0.036$ ;  $sex_{(women)}=-57.7\pm 26.1$  N·m,  $t_{(1,25)}=-2.2$ ,  $P=0.037$ ]. For the rate of torque development, one outlier  
247 was identified (epee woman) showing a steep increase in the rate of torque development values (663 to 1166  
248 N·m·s<sup>-1</sup>). The rate of torque development did not change over time ( $P=0.08$ ), with greater values for men  
249 compared to women [ $I=1041.8\pm 54.8$  N·m·s<sup>-1</sup>,  $t_{(1,26)}=19$ ,  $P<0.001$ ;  $sex_{(women)}=-217.5\pm 92$  N·m·s<sup>-1</sup>,  $t_{(1,26)}=-2.4$ ,  
250  $P=0.026$ ]. The amplitude of the potentiated doublet was unchanged after the bout ( $P=0.87$ ) and was not  
251 different across sexes ( $P=0.17$ ), with  $I=130.6\pm 7.2$  N·m ( $t_{(1,23)}=18$ ;  $P<0.001$ ). For voluntary activation, one  
252 participant (epee man) was excluded due to invalid data at *post*. Voluntary activation ( $n=13$ ) was similar  
253 across sexes ( $P=0.79$ ) but decreased with time [ $I=84\pm 2\%$ ,  $t_{(1,22)}=44.6$ ,  $P<0.001$ ;  $bout_{(0,1)}=-5\pm 2\%$ ,  $t_{(1,14)}=-2.5$ ,  
254  $P=0.028$ ]. Percentage differences from *pre* to *post* are presented in Figure 1.

255

256 \*\*\*Figure 1 about here\*\*\*

257

### 258 3.1.2 Effect of a simulated competition

259 No main effects of weapon and bout result were found for the neuromuscular variables (all  $P>0.05$ ). Those  
260 effects were thus removed from the models for subsequent analyses. For CMJ, one outlier was identified  
261 (epee man) showing a steep decrease in CMJ across the competition (from 49 to 36 cm). CMJ did not show  
262 significant changes across the competition ( $P=0.059$ ), being greater for men than women [ $I=42.5\pm 0.9$  cm,  
263  $t_{(1,25)}=47.4$ ,  $P<0.001$ ;  $sex_{(women)}=-9.7\pm 1.5$  cm,  $t_{(1,25)}=-6.6$ ,  $P<0.001$ , Figure 2A]. Maximal torque did not show  
264 a significant sex main effect ( $P=0.082$ ), but it decreased along the competition [ $I=274.1\pm 12.9$  N·m,  
265  $t_{(1,31)}=21.2$ ,  $P<0.001$ ;  $bout_{(0,4)}=-4.4\pm 1.8$  N·m,  $t_{(1,52)}=-2.5$ ,  $P=0.017$ , Figure 2B]. One outlier was found for the  
266 rate of force development (saber man), showing a steep increase in the rate of torque development values  
267 from the end of the first bout (555 N·m·s<sup>-1</sup>) to the end of the competition (882 N·m·s<sup>-1</sup>). The rate of torque  
268 development was greater for men than women and decreased along the competition [ $I=1033.6\pm 49.8$  N·m·s<sup>-1</sup>,  
269  $t_{(1,29)}=20.8$ ,  $P<0.001$ ;  $bout_{(0,4)}=-24.3\pm 6.0$  N·m·s<sup>-1</sup>,  $t_{(1,25)}=-4.0$ ,  $P<0.001$ ;  $sex_{(women)}=-176.9\pm 79.9$  N·m·s<sup>-1</sup>,  
270  $t_{(1,27)}=-2.2$ ,  $P=0.036$ , Figure 2C]. One outlier was detected for the potentiated doublet (epee man, the same as  
271 CMJ), which showed a steep decrease from the end of the first bout (150 N·m) to the end of the competition  
272 (52 N·m). The amplitude of the potentiated doublet did not change from the end of the first bout to the end of  
273 the competition ( $P=0.73$ ) nor the difference between sexes was observed ( $P=0.37$ ), [ $I=129.3\pm 7.0$  N·m·s<sup>-1</sup>,  
274  $t_{(1,24)}=18.5$ ,  $P<0.001$ , Figure 2D]. For voluntary activation, one outlier was detected (epee man), who showed  
275 a steep decrease in voluntary activation values from the end of the first bout (83%) to the end of the  
276 competition (53%). Voluntary activation did not change between sexes ( $P=0.39$ ) or across the competition  
277 ( $P=0.53$ ); [ $I=79.9\pm 1.5$  N·m·s<sup>-1</sup>,  $t_{(1,14)}=53$ ,  $P<0.001$ , Figure 2E].

278

279 \*\*\*Figure 2 about here\*\*\*

280

## 281 3.2 Subjective measurements

### 282 3.2.1 Perception of Fatigue and Effort

283 No main effects of weapon and bout results were found for fatigue ( $P=0.60$ ;  $P=0.25$ ) and effort ( $P=0.12$ ;  
284  $P=0.14$ ). For fatigue, no significant sex effect was found ( $P=0.57$ ). Significant bout  $\times$  period interaction was  
285 found for fatigue. As the competition progressed, *pre* bout fatigue increased, with lower differences at *post*  
286 between bouts [ $I=4.83\pm 0.35$  cm,  $t_{(1,41)}=12.2$ ,  $P<0.001$ ;  $\text{period}_{(0,3)}=0.7\pm 0.1$  cm,  $t_{(1,422)}=7.05$ ,  $P<0.001$ ,  
287  $\text{bout}_{(0,4)}=0.58\pm 0.07$  cm,  $t_{(1,422)}=8.47$ ,  $P<0.001$ ,  $\text{period}_{(0,3)}\times\text{bout}_{(0,4)}=-0.14\pm 0.04$  cm,  $t_{(1,422)}=-3.33$ ,  $P<0.001$ ,  
288 Figure 3A]. For effort, significant period and bout main effects were found, indicating an increase in effort  
289 along the bout and throughout the competition [ $I=5.45\pm 0.31$  cm,  $t_{(1,46)}=17.5$ ,  $P<0.001$ ;  $\text{period}_{(0,2)}=0.54\pm 0.12$   
290 cm,  $t_{(1,300)}=4.42$ ,  $P<0.001$ ,  $\text{bout}_{(0,4)}=0.16\pm 0.06$  cm,  $t_{(1,297)}=2.55$ ,  $P=0.011$ , Figure 3B].

291

292 \*\*\*Figure 3 about here\*\*\*

293

### 294 3.2.2 Perceived Workload

295 Because mental demand was modelled assuming beta distribution due to skewed data, glmmTMB was used  
296 to model all linear-mixed models for NASA<sub>TLX</sub> dimensions to be consistent in data reporting. Effort  
297 presented no weapon ( $P=0.22$ ), sex ( $P=0.51$ ) or bout ( $P=0.38$ ) main effects. The effort was reported as  
298 greater in the case of victory [ $I=61\pm 3$  A.U.,  $z=20.2$ ,  $P<0.001$ ;  $\text{result}_{(\text{victory})}=7\pm 3$  A.U.,  $z=2.1$ ,  $P=0.03$ ].  
299 Physical demand presented no weapon ( $P=0.21$ ), sex ( $P=0.30$ ), bout ( $P=0.07$ ) or result ( $P=0.20$ ) main effect  
300 [ $I=65\pm 3$  A.U.  $z=24$ ,  $P<0.001$ ]. Mental demand presented one outlier (saber woman), who reported a very  
301 low score (5 A.U. over 100 A.U.) in the last bout (ended with a defeat). Mental demand did not present  
302 weapon ( $P=0.55$ ) or sex ( $P=0.35$ ) main effects, but it increased throughout the competition and was greater  
303 in case of victory [beta-distribution (mental demand $\times 100^{-1}$ ), logit estimates:  $I=0.53\pm 0.21$ ,  $z=2.5$ ,  $P<0.001$ ;  
304  $\text{bout}_{(0,4)}=0.11\pm 0.5$ ,  $z=2.3$ ,  $P=0.024$ ;  $\text{result}_{(\text{victory})}=0.30\pm 0.15$ ,  $z=2.04$ ,  $P=0.042$ ]. For mental demand, estimates  
305 were computed using the ggpredict package for R<sup>28</sup> and presented in Figure 4. Frustration did not present  
306 weapon ( $P=0.45$ ), sex ( $P=0.43$ ) or bout ( $P=0.06$ ) main effects but it was scored higher when the bout was lost  
307 [ $I=63\pm 4$  A.U.,  $z=15.9$ ,  $P<0.001$ ;  $\text{result}_{(\text{victory})}=-22\pm 4$  A.U.,  $z=-5.8$ ,  $P<0.001$ ]. Perceived performance did not  
308 present weapon ( $P=0.65$ ), sex ( $P=0.68$ ) or bout ( $P=0.81$ ) main effects, but was perceived as greater when the  
309 bout was won [ $I=38\pm 3$  A.U.,  $z=11.4$ ,  $P<0.001$ ;  $\text{result}_{(\text{victory})}=-24\pm 4$  A.U.,  $z=-6.9$ ,  $P<0.001$ ]. Temporal pressure  
310 did not show weapon ( $P=0.08$ ), sex ( $P=0.50$ ), bout ( $P=0.53$ ) or result ( $P=0.31$ ) main effects [ $I=52\pm 4$  A.U.,  
311  $z=14.3$ ,  $P<0.001$ ]. The effect of the bout's result (victory or defeat) is presented in Appendix C using the  
312 estimated density function for the NASA<sub>TLX</sub> scores. We observed a generalizable high mental and physical  
313 demand and considerable effort in the task.

314

315 \*\*\*Figure 4 about here\*\*\*

316

## 317 **4. DISCUSSION**

318 In the present study, we aimed to evaluate fatigue induced by a simulated competition in fencing. The  
319 strengths and novelties of our study were the inclusion of elite athletes for all three fencing weapons and the  
320 consideration of objective and subjective manifestations of fatigue.

321 The main results reveal: (i) a meaningful impairment in knee extensor rate of torque development ability  
322 after the simulated competition; (ii) an increase in perceived effort, fatigue, and mental demand across the  
323 competition. Results also indicate that (iii) fencing is characterized by an important effort required to win a  
324 bout. These results support our hypothesis, demonstrating that a simulated competition has a limited impact  
325 on the knee extensors' neuromuscular function, but induces an increase in the perception of fatigue  
326 associated with an important perceived mental demand that increases along the competition.

327

### 328 **4.1 Characteristics of a fencing bout**

329 Regarding our data on the neuromuscular function, after a single fencing bout we observed an increase in  
330 CMJ height and a concomitant decrease in maximal torque and voluntary activation. However, regarding  
331 CMJ height and maximal torque, the changes were inferior to the standard errors estimated by the model,  
332 suggesting that these changes might not be meaningful. Indeed, by plotting the percentage changes from *pre*  
333 to *post* bouts (see Figure 1), all the points clustered around zero. It is important to note that maximal torque  
334 was 12% lower at baseline the day of the competition compared to the familiarization (Appendix D).

335 Potentiated doublet and rate of torque development were similar between days. Therefore, we cannot rule out  
336 the possible underestimation of maximal strength loss after the first bout in the present study. It is likely that,  
337 on the day of the simulated competition, athletes were prioritizing their engagement in the fencing bouts  
338 rather than in the maximal voluntary contraction, despite the instructions and encouragements provided by  
339 the researchers. The low reliability and agreement analyses for maximal torque and voluntary activation  
340 presented in Appendix D suggest that caution must be taken when interpreting these changes. Regarding the  
341 possible increase in CMJ, similar results has been previously documented in fencing.<sup>4</sup> CMJ showed an  
342 excellent reliability and agreement, and this increase might be due to the post-activation performance  
343 enhancement of the first bout that counterbalanced the possible fatigue-related impairments.<sup>29</sup>

344 Following a single bout, fencers perceived high levels of effort, mental and physical demands. As effort  
345 refers to the engagement of physical and cognitive resources to perform in a task,<sup>14-16</sup> a concomitant increase  
346 in mental and physical demand could be expected. This was likely due to the rapid and successive  
347 recruitment of motor units and motor control demand of the task needed to attack or defend (physical  
348 demand) and the continuous attention to the movement of the opponent, as well as the rapid and continuous  
349 information processing needed to take accurate decisions (mental demand). The short duration of assaults  
350 and recovery time between bouts was likely sufficient to avoid fatigability of the knee extensors in elite  
351 fencers.

352

#### 353 **4.2 Evolution of fatigue during a fencing simulated competition**

354 During the simulated competition, we observed a slight decrease in maximal torque and rate of torque  
355 development (-1.6% and -2.4% per bout, respectively), which was not accompanied by changes in  
356 potentiated doublet or voluntary activation. Furthermore, CMJ height did not decrease. This was not  
357 surprising as some authors previously suggested that CMJ height might not be a sensitive index of fatigue in  
358 fencing.<sup>4</sup> It is also possible that the period of recovery between assaults, periods and bouts was sufficient to  
359 limit the development of neuromuscular fatigue. Indeed, previous studies focusing on energetics, reported  
360 limited blood lactate accumulation<sup>4,30,31</sup> and time passed above the anaerobic ventilatory threshold.<sup>30</sup> A more  
361 in-deeper analysis of the energetic profiling of fencing competition showed a predominance of aerobic and  
362 anaerobic alactic processes (e.g. the use of phosphocreatine for the ATP-resynthesis) to support fencing  
363 assaults,<sup>31</sup> allowing a rapid recovery kinetic and thus probably limiting the development of neuromuscular  
364 impairments. Although the decreased maximal torque of ~17.8 N·m for the simulated competition might be  
365 considered as limited, the decreased rate of torque development was ~100 N·m·s<sup>-1</sup> (~10%). This loss in rate  
366 of torque development could be relevant, considering that recently it has been reported a loss of ~15%  
367 following an intense downhill running session using similar methods.<sup>32</sup> The decrease in the rate of torque  
368 development would indicate an impairment in the ability to rapidly develop muscle force along a competition  
369 day, and could be a more appropriate measure than maximal torque to detect alteration in neuromuscular  
370 function induced by fast contractions.<sup>13</sup>

371 This is the first study that studied both fatigue and effort in fencing. Fencers perceived about 12% higher  
372 level of fatigue for each successive bout. Effort increased by 10% for each period during the bout. Across  
373 bouts, we observed a slight general increased in perceived effort (about 3%). Previously, no differences  
374 between post-bouts were found during the direct elimination phase of the competition.<sup>4,11</sup> Indeed, the effort  
375 item on the NASA<sub>TLX</sub> (administered only after each bout) showed in no significant time effect. As effort  
376 differs from fatigue and other exercise-related perceptions [for more information see<sup>15</sup> and<sup>16</sup>], it is likely that,  
377 by rating separately fatigue and effort, as well as acquiring data between and within bouts, we were able to  
378 detect small changes in these two parameters. Differences with the literature could also be due to the greater  
379 sample size in this study, leading to a higher statistical power [29 vs. 9,<sup>4</sup> and 8.<sup>11</sup>]. Importantly, the mental  
380 demand increased during the competition, and a higher mental demand was perceived in case of victory.  
381 Taken together, these results suggest that fatigue induced by a fencing competition could have a strong  
382 cognitive component, traditionally referred to as cognitive or mental fatigue.<sup>5</sup> As changes in these  
383 perceptions are subjective manifestations of cognitive fatigue, future studies should quantify objective  
384 manifestations such as changes in cognitive performance – *i.e.*, cognitive fatigability – to further extend this  
385 observation.

386

#### 387 **4.3 Weapon- and sex-related differences**

388 We did not observe any effect of the fencing weapon on the variables studied. This result could be  
389 underpowered due to the low number of participants per weapon. It also suggests that no evident pattern  
390 emerged. Regarding sex-related differences, except for the neuromuscular variables at baseline, we did not  
391 observe any sex-related differences in fatigability, effort, fatigue, and workload. This suggests that the  
392 impact of the simulated competition on both neuromuscular and perceptual/subjective variables was similar  
393 between men and women competing against peers matched for sex and fencing level. This does not exclude  
394 a difference in the absolute intensity of the task across groups. Indeed, the lack of an objective external  
395 workload (e.g., distance covered during the assaults) held us to perform a standardized comparison across  
396 sexes.

397

#### 398 **4.4 Limitations**

399 The main limitation of the present study was that not all athletes during the simulated competition fulfilled  
400 the instructions of performing maximal contractions during neuromuscular testing or did not tolerate the  
401 associated electrical stimulation, reducing the maximal torque exerted in case of stimulations. Contrary to  
402 maximal torque and voluntary activation that are dependent on the voluntary engagement of the fencers, the  
403 potentiated doublet obtained at rest, in the absence of voluntary engagement of the fencers, was similar  
404 between days. However, we are confident that our analysis addressed this limitation: although the 70%  
405 threshold was arbitrary, participants showing values >70% of voluntary activation were clustered when  
406 plotted against the other indices of fatigability such as maximal torque, rate of torque development or  
407 potentiated doublet (data presented in Appendix E). Another limitation was the imbalanced number of men  
408 and women and across weapons, limiting our analysis when evaluating sex and weapon differences. Finally,  
409 we cannot rule out the possibility that the simulated competition presented a lower intensity compared to a  
410 real international competition, leading to an underestimation of the neuromuscular impairments caused by  
411 the competition and different perceived fatigue, effort and workload.

412

#### 413 **5. PERSPECTIVES**

414 To cope with the competition-related demands and maintain optimal performance, or counterbalance the  
415 effect of increasing fatigue across the bouts and the competition, fencers needed to increase the allocation of  
416 mental resources to the task. Future interventions aiming to improve fencing performance should consider  
417 training the mental skills of fencers, to help them cope with the important mental demand of the competition.  
418 Furthermore, as we observed that frustration was greater, and perceived performance lower, in case of defeat  
419 (Appendix C), interventions aiming to manage stress and frustration following a lost bout or a lost *assault*,  
420 could also be of great interest to coaches and fencers. The rate of force development was the sole  
421 neuromuscular variable impaired by the simulated competition, suggesting that this variable could be of  
422 interest to strength and conditioning coaches in monitoring the training of fencers.

423

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428 competitions. We sincerely thank all the coaches and the athletes for their participation.

429

### 430 **Competing interests**

431 The authors declare that they have no competing interests.

432

### 433 **Data statement**

434 The research data will be kept confidential until the end of the Olympic Games in Paris 2024.

435

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439

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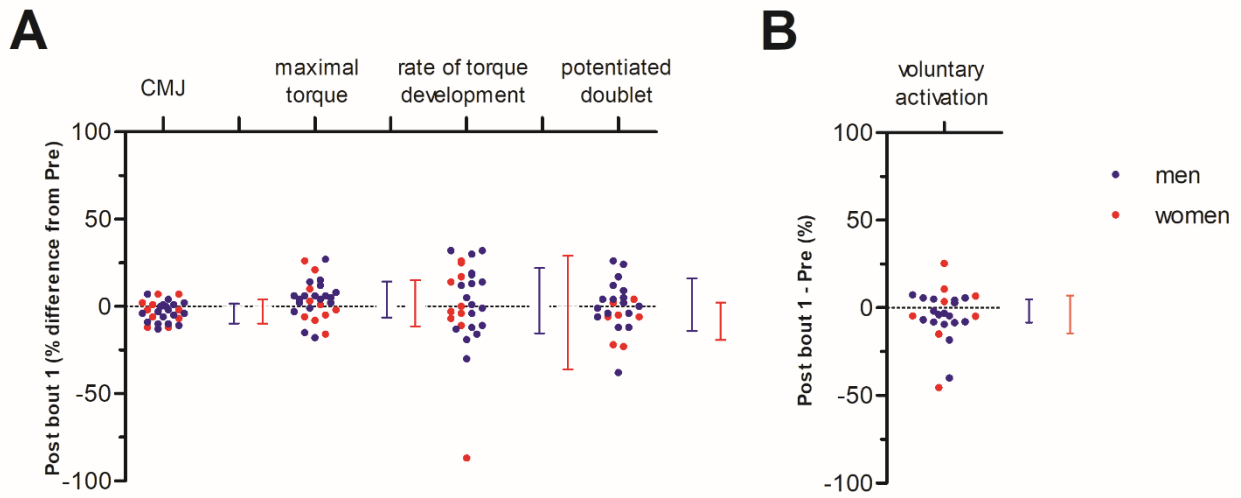
524 **Table 1.** Participants' characteristics were divided by team measured during the familiarization session.

	Epee		Saber		Foil
	Men (n=6)	Women (n=6)	Men (n=6)	Women (n=5)	Men (n=6)
<b>Age (yr)</b>	29 ± 5	27 ± 4	23 ± 2	23 ± 2	23 ± 2
<b>Height (cm)</b>	184 ± 8	178 ± 8	181 ± 4	177 ± 4	187 ± 6
<b>Body mass (kg)</b>	82 ± 11	66 ± 3	77 ± 8	68 ± 6	81 ± 6
<b>Ranking (median and range)</b>	12 [4, 115]	31 [4, 88]	111 [53, 311]	43 [25, 281]	56 [37, 104]
<b>CMJ (cm)</b>	43 ± 8	30 ± 3	41 ± 5	34 ± 5	39 ± 4
<b>Maximal torque (N·m)</b>	330 ± 64	318 ± 63	302 ± 54	271 ± 62	339 ± 75
<b>Rate of force development (N·m·s<sup>-1</sup>)</b>	1222 ± 99	1021 ± 202	1050 ± 288	1103 ± 276	1168 ± 161
<b>Potentiated doublet (N·m)</b>	128 ± 43	104 ± 22	120 ± 24	135 ± 36	162 ± 25
<b>Voluntary activation (%) (median ± IQR)*</b>	90 ± 2	93 ± 1	83 ± 9	91 ± 1	92 ± 6

525 Data are presented as mean ± SD unless otherwise specified. The ranking represents the world ranking  
526 position of athletes at the moment of the study.\*For voluntary activation, data were available for 14  
527 participants (2 epee men, 3 epee women, 3 saber men, 2 saber women, and 4 foil men). CMJ =  
528 countermovement jump; IQR = interquartile range.

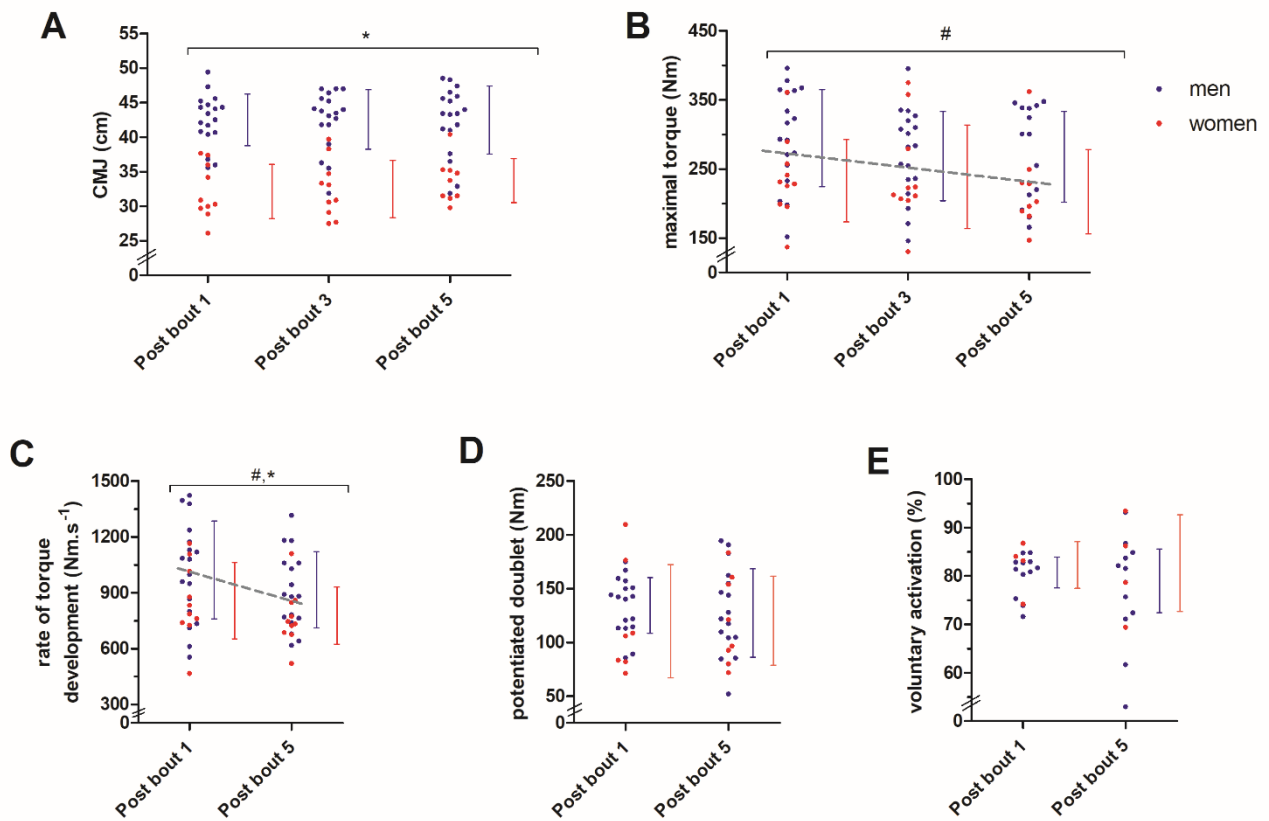
530 **Figures**

531 **Figure 1.**



532

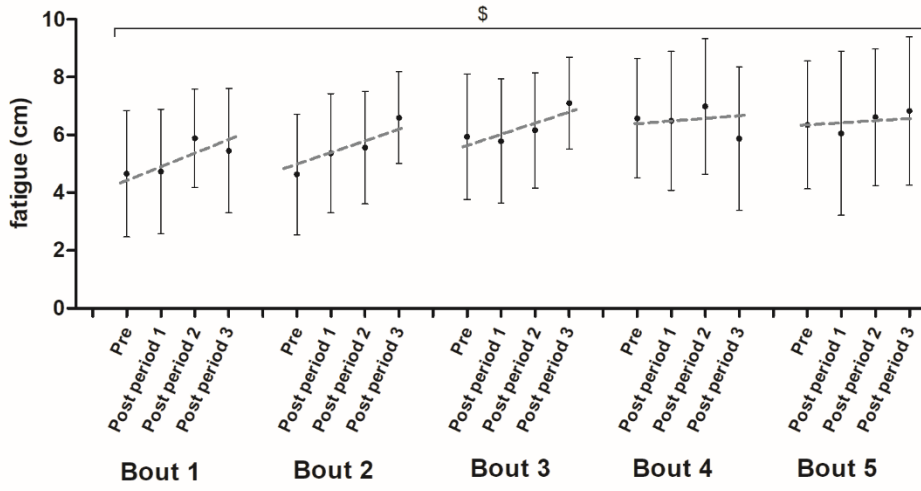
533 **Figure 2.**



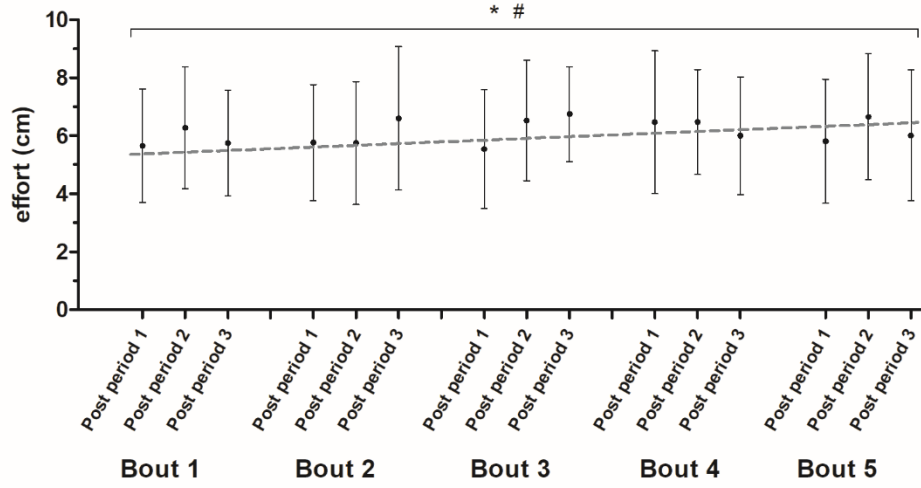
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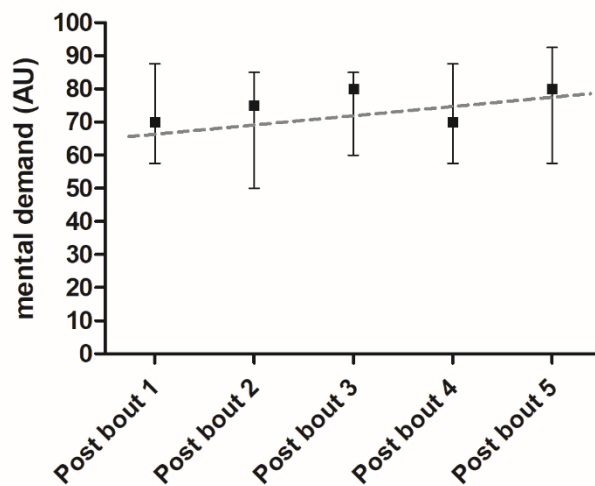
**A**



**B**



537



539

540 **Figures caption**

541

542 Figure 1. *Effects of a single fencing bout on the knee extensors' neuromuscular function in men (blue) and*  
543 *women (red). Panel A presents neuromuscular data as a percentage difference from pre (Panel A). Vertical*  
544 *lines represent the mean  $\pm$  SD. Panel B presents data for voluntary activation where values at post were*  
545 *subtracted from values at pre, and presented as median  $\pm$  IQR. CMJ = countermovement jump.*

546

547 Figure 2. *Evolution of the knee extensors' neuromuscular function after the bouts of the simulated*  
548 *competition in men (blue) and women (red). Vertical lines represent the mean  $\pm$  SD for Panels A, B, C and*  
549 *D. The dotted line indicates the estimates from the mixed model (bout effect). Panel A presents data for*  
550 *countermovement jump (CMJ) after bouts 1, 3 and 5. Panel B presents data for maximal torque after bouts*  
551 *1, 3 and 5. Panel C presents data for the rate of torque development calculated over 200 ms after bouts 1, 3*  
552 *and 5. Panel D presents data for potentiated 100 Hz doublet evoked 2-s following the maximal voluntary*  
553 *contraction after bouts 1 and 5. Panel E presents data for voluntary activation after bouts 1 and 5, vertical*  
554 *lines represent the median  $\pm$  IQR. \*significant sex-related difference ( $P < 0.05$ ). #significant effect of bout ( $P$*   
555  *$< 0.05$ ).*

556

557 Figure 3. *Evolution of the subjective data of the perceived fatigue and effort collected using visual analog*  
558 *scales of 10 cm. Data are presented as mean  $\pm$  SD. The dotted line indicates the estimates from the mixed*  
559 *model. Panel A presents the evolution of the perceived fatigue during the simulated competition, only the*  
560 *effect of period was presented for clarity. Panel B presents the evolution of perceived effort during the*  
561 *simulated competition, only the bout main effect is presented for clarity. \*significant effect of period ( $P <$*   
562  *$0.05$ ). #significant effect of bout ( $P < 0.05$ ). \$significant bout  $\times$  period interaction ( $P < 0.05$ ).*

563

564 Figure 4. *Evolution of the perceived mental demand measured with the NASA TLX scale. Data are presented*  
565 *as median  $\pm$  interquartile range. The dotted line indicates the estimates from the mixed model.*

566