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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 ¹]. 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.¹

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,² foil = 5s:15s,¹ saber = 3s:15s.³].

73 As other combat sports, fencing practice induces fatigue.⁴ 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.^{5,6} 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.^{6,7}
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.⁸ 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.^{2,9-11} Limited evidence is available on the
84 performance of the neuromuscular system.⁴ 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.^{10,12} A previous study evaluating countermovement jump height (CMJ) observed no change
87 following a fencing competition.⁴ 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.⁴ 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.¹³ 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,⁶ namely
94 the perception of effort.¹⁴⁻¹⁶ 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",^{2,4,11} with stable ratings along a competition.⁴ 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,^{1,2,17} 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.⁴ 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 ± 0.5 days/week and for 5 ± 1 hours/day. The average time dedicated to technical training
121 was 3 ± 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*”^{2,11}. 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’Escrime (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.¹⁸ 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.¹⁹⁻²¹).

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_{TLX}) questionnaire for measuring the perceived workload of each bout.^{22,23} 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_{TLX} 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_{TLX}
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?".²² 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).²⁴ 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_{TLX} 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.²⁵ The
210 glmmTMB package²⁶ 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_{TLX}). P-values were extracted from all F-tests using Satterthwaite's degrees of
213 freedom method [lmerTest package²⁷]. 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⁻¹). 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⁻¹, $t_{(1,26)}=19$, $P<0.001$; $sex_{(women)}=-217.5\pm 92$ N·m·s⁻¹, $t_{(1,26)}=-2.4$,
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⁻¹) to the end of the competition (882 N·m·s⁻¹). 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⁻¹,
269 $t_{(1,29)}=20.8$, $P<0.001$; $bout_{(0,4)}=-24.3\pm 6.0$ N·m·s⁻¹, $t_{(1,25)}=-4.0$, $P<0.001$; $sex_{(women)}=-176.9\pm 79.9$ N·m·s⁻¹,
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⁻¹,
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⁻¹, $t_{(1,14)}=53$, $P<0.001$, 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_{TLX} 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 R²⁸ 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_{TLX} 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.⁴ 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.²⁹

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,¹⁴⁻¹⁶ 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.⁴ 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^{4,30,31} and time passed above the anaerobic ventilatory threshold.³⁰ 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,³¹ 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⁻¹ (~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.³² 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.¹³

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.^{4,11} Indeed, the effort
375 item on the NASA_{TLX} (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 see¹⁵ and¹⁶], 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. 9,⁴ and 8.¹¹]. 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.⁵ 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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519 rate of force development. *Eur J Appl Physiol*. Published online 2022;11. doi:doi.org/10.1007/s00421-
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522

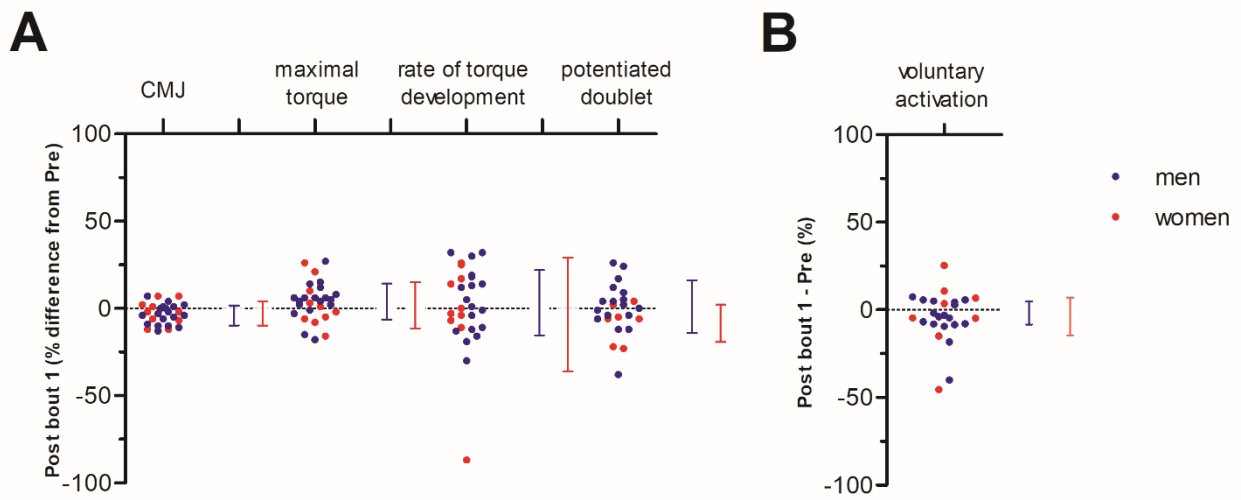
524 **Table 1.** Participants' characteristics were divided by team measured during the familiarization session.

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

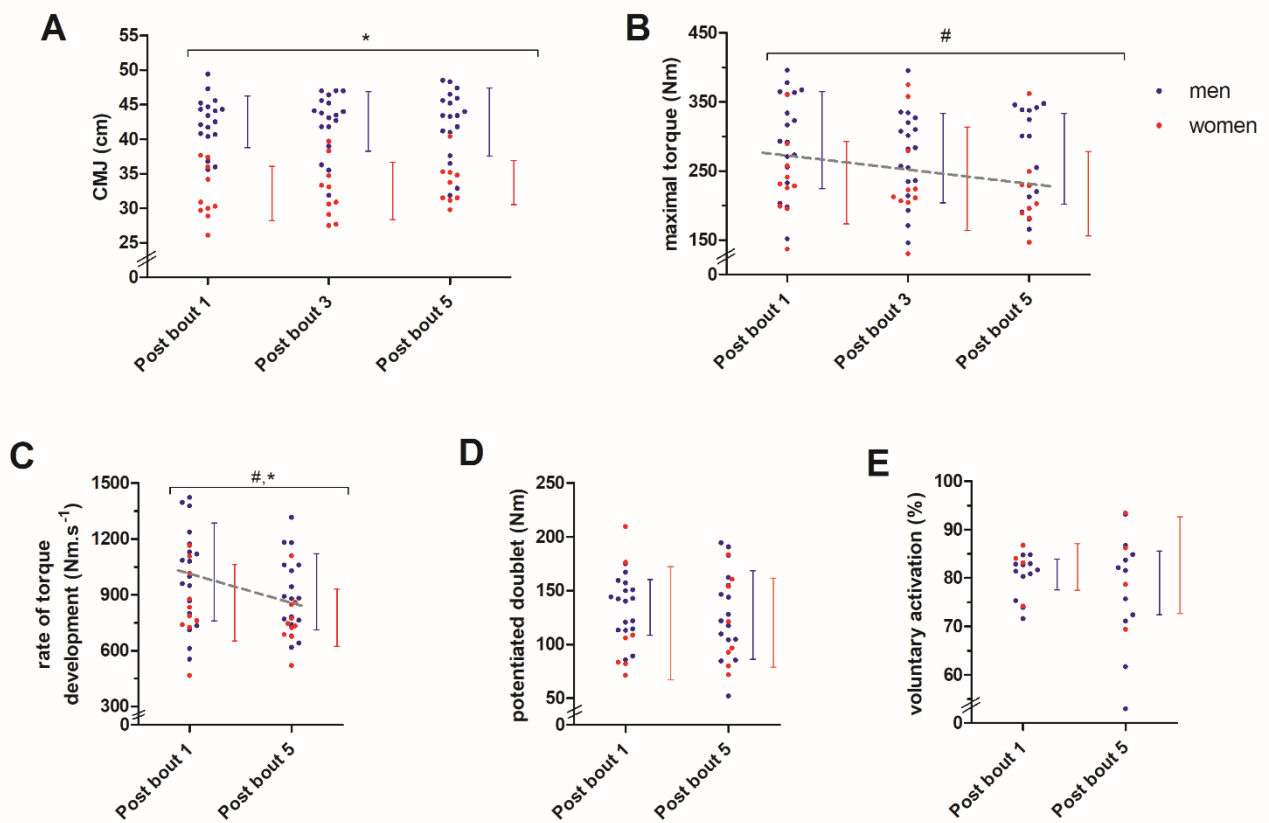
530 **Figures**

531 **Figure 1.**



532

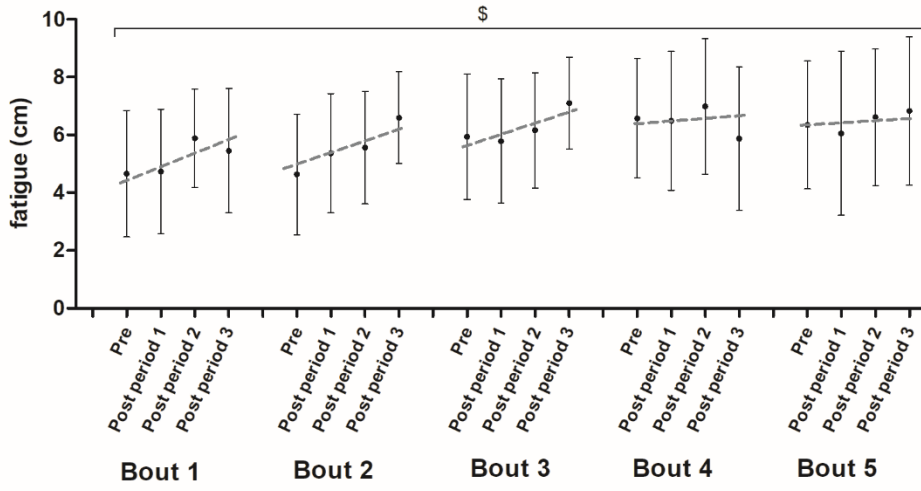
533 **Figure 2.**



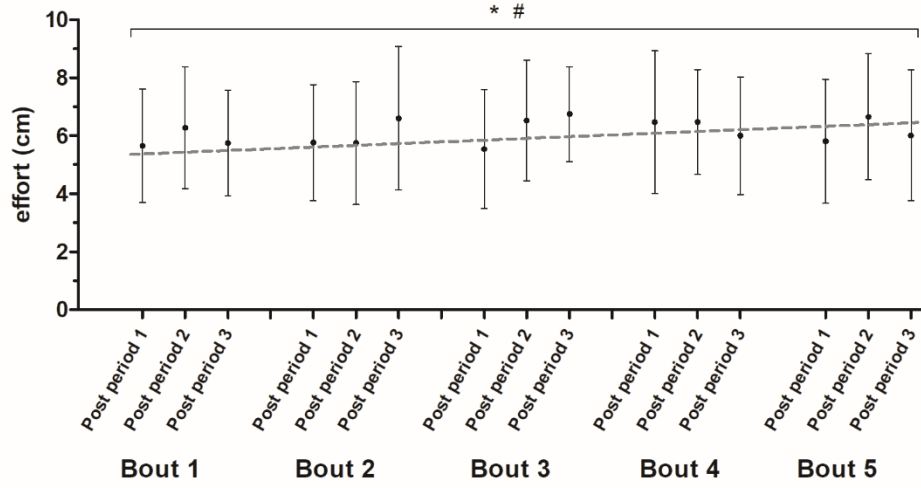
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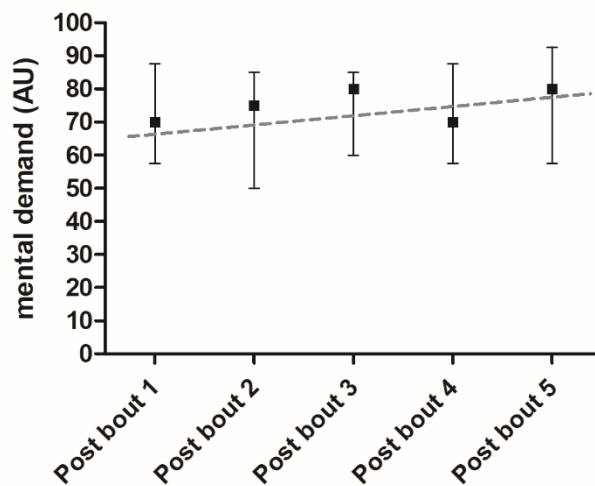
A



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