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1 Manuscript title: Sex-related changes in physical performance,  
2 wellbeing and neuromuscular function of elite Touch players  
3 during a four-day international tournament.

4 **Abstract**

5

6 **Purpose:** To examine the within- and between-sex physical  
7 performance, wellbeing and neuromuscular function responses  
8 across a four-day international touch rugby (Touch) tournament.

9 **Methods:** Twenty females and twenty-one males completed  
10 measures of wellbeing (fatigue, soreness, sleep, mood, stress)  
11 and neuromuscular function (countermovement jump (CMJ)  
12 height, peak power output (PPO) and peak force (PF)) during a  
13 4-day tournament with internal, external and perceptual loads  
14 recorded for all matches. **Results:** Relative and absolute total,  
15 low- (*females*) and high-intensity distance was lower on day 3  
16 (*males and females*) (ES = -0.37 to -0.71) compared to day 1.  
17 Mean heart rate was *possibly to most likely* reduced during the  
18 tournament (except day 2 males) (ES = -0.36 to -0.74), whilst  
19 RPE-TL was consistently higher in females (ES = 0.02 to 0.83).  
20 The change in mean fatigue, soreness and overall wellbeing were  
21 *unclear to most likely* lower (ES = -0.33 to -1.90) across the  
22 tournament for both sexes, with greater perceived fatigue and  
23 soreness in females on days 3-4 (ES = 0.39 to 0.78). Jump height  
24 and PPO were *possibly to most likely* lower across days 2-4 (ES  
25 = -0.30 to -0.84), with greater reductions in females (ES = 0.21  
26 to 0.66). Wellbeing, CMJ height, and PF were associated with  
27 changes in external, internal and perceptual measures of load  
28 across the tournament ( $\eta^2$  = -0.37 to 0.39). **Conclusions:** Elite  
29 Touch players experience reductions in wellbeing,

30 neuromuscular function and running performance across a 4-day  
31 tournament, with notable differences in fatigue and running  
32 between males and females, suggesting sex-specific monitoring  
33 and intervention strategies are necessary.

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76 **Introduction**

77  
78 Touch rugby (Touch) is an intermittent team sport that is played  
79 globally at regional, national and international standards, and is  
80 characterised by frequent periods of high-intensity activity  
81 interspersed with periods of passive recovery during  
82 interchanges.<sup>1-3</sup> The use of microtechnology that incorporates a  
83 global positioning system and accelerometer have been used  
84 extensively in team sports, though limited studies have  
85 documented the internal and external demands of Touch, with  
86 research limited to single-sex teams, using a single match<sup>1,3</sup> and  
87 one across an entire tournament.<sup>2</sup> For a single match, it was  
88 reported that international male players perform ~9 bouts of  
89 activity each lasting approximately 148 seconds, resulting in a  
90 mean playing time of  $16.52 \pm 5.50$  minutes.<sup>1</sup> During this time,  
91 players cover mean total, low-intensity ( $< 14 \text{ km}\cdot\text{h}^{-1}$ ), high-  
92 intensity ( $> 14 \text{ km}\cdot\text{h}^{-1}$ ) and very high-intensity ( $> 20 \text{ km}\cdot\text{h}^{-1}$ )  
93 distances of  $2266 \pm 594 \text{ m}$  ( $137 \pm 13.6 \text{ m}\cdot\text{min}^{-1}$ ),  $1651 \pm 594 \text{ m}$   
94 ( $98.2 \pm 6.4 \text{ m}\cdot\text{min}^{-1}$ ),  $620 \pm 155 \text{ m}$  ( $39.3 \pm 12.0 \text{ m}\cdot\text{min}^{-1}$ ) and  $119$   
95  $\pm 60 \text{ m}$  ( $7.67 \pm 4.40 \text{ m}\cdot\text{min}^{-1}$ ), respectively.<sup>1</sup> During the course  
96 of an international competition, female players competed in 9-  
97 10 matches over four consecutive days with high-intensity  
98 distance (i.e. match 1 =  $29.3 \pm 14.8 \text{ m}\cdot\text{min}^{-1}$ ) greatest on day one  
99 but progressively declining by day three (i.e. match 7 =  $18.2 \pm$   
100  $96.9 \text{ m}\cdot\text{min}^{-1}$ ).<sup>2</sup> Furthermore, Marsh et al.<sup>2</sup> reported on the  
101 change in time spent at high metabolic power ( $20 \text{ W}\cdot\text{kg}^{-1}$ ), which

102 was reduced on day three compared to day one. The use of high  
103 metabolic power, alongside more traditional measures of  
104 movement, offers a more comprehensive appraisal of the load  
105 imposed on athletes where multiple directional changes are  
106 involved.<sup>4</sup> Research using a range of movement characteristics  
107 is warranted to report the loads imposed on elite Touch players  
108 of both sexes during a tournament and to what extent the these  
109 loads change in subsequent matches.<sup>5</sup>

110

111 International Touch players typically compete in a tournament-  
112 style competition that comprises multiple matches over a three-  
113 or four-day period. The neuromuscular, physiological and  
114 cognitive perturbations associated with team sport athletes  
115 involved in congested fixtures is of interest given the potential  
116 negative impact on players' wellbeing and physical  
117 performance<sup>5-7</sup> as well as potential for increased injury risk.  
118 During a two-day international rugby sevens competition where  
119 female players competed in 4-6 matches, perceived wellbeing  
120 decreased substantially with players reporting greater muscle  
121 soreness at the end of the tournament.<sup>6</sup> During a junior rugby  
122 league tournament where players performed in five matches over  
123 a five-day period, a progressive decrease in wellbeing and  
124 neuromuscular function was observed, which was negatively  
125 associated with several performance variables including relative  
126 distance, high-speed running and number of repeated high-

127 intensity efforts.<sup>8</sup> It is important to note that rugby sevens and  
128 rugby league both involve contact, which will likely influence  
129 measures of fatigue and exercise-induced muscle damage  
130 (EIMD).<sup>5</sup> Nonetheless, Hogarth et al.<sup>7</sup> reported a progressive  
131 decrease in wellbeing, while changes in jump height were  
132 unclear during a tag rugby competition that required male  
133 players to compete in three matches interspersed with 90-  
134 minutes recovery. The authors also reported that increased  
135 neuromuscular and perceptual fatigue over consecutive matches  
136 were associated with reductions in match running performance.<sup>6</sup>  
137 Further work is required to elucidate changes in wellbeing and  
138 neuromuscular function over the course of a Touch tournament,  
139 as well as the influence of any changes on match running  
140 performance.

141

142 Current evidence on fatigue and EIMD from intermittent team  
143 sports is largely limited to single-sex groups. It is likely that  
144 reductions in performance capability from intermittent activity  
145 are specific to the demands of the task, the muscle activity and  
146 the physical characteristics of the individual, including sex.<sup>9</sup> For  
147 example, Hunter<sup>10</sup> reported that total muscle mass, proportional  
148 area of muscle fibres, contractile properties, mechanical  
149 compression and initial strength influences the magnitude of  
150 impairment during fatiguing exercises, which offers a possible  
151 explanation for the different fatigability in males and females.

152 However, sex differences in muscle force generating capability  
153 after damaging exercise remain unclear, with either no  
154 difference between sexes<sup>11-15</sup> or greater losses for females  
155 compared to males.<sup>16</sup> While differences in muscle fatigability  
156 between males and females has been studied during isolated  
157 tasks that involve isometric or dynamic muscle  
158 contractions,<sup>9,13,16</sup> and repeated sprint exercise,<sup>17</sup> changes in  
159 muscle function of intermittent team sports athletes involved in  
160 repeated activities over several days is unknown. Understanding  
161 the fatigue and EIMD characteristics of male and female Touch  
162 players within the sporting environment, rather than laboratory,  
163 is important for informing coaches', tactical decisions and  
164 targeting pertinent recovery strategies.

165

166 The primary aim of this study was to examine the differences in  
167 match characteristics, neuromuscular function and perceived  
168 wellbeing between elite male and female Touch players during a  
169 four-day international tournament. A secondary aim was to  
170 explore the association between neuromuscular function and  
171 perceived wellbeing with measures of match workload.

172

## 173 **Methods**

174

### 175 *Participants and design*

176

177 With institutional ethics approval, 21 male (age =  $26.3 \pm 5.4$  y,  
178 mass =  $75.8 \pm 8.0$  kg, stature =  $176.9 \pm 5.7$  cm) and 20 female  
179 (age =  $26.4 \pm 5.6$  y, mass =  $60.1 \pm 6.2$  kg, stature =  $163.3 \pm 5.3$



180 cm) international Touch players from same national team  
181 volunteered to participate in the study. All players had been  
182 prepared for the tournament over an 18-week period including  
183 formalised training, testing and a skills programme delivered by  
184 the nation's high-performance team. Players were monitored  
185 during a four-day international tournament comprising two or  
186 three matches per day starting between 08:30 and 10:00 on each  
187 morning, and with between 160 and 178 minutes between  
188 matches.

189  
190 One week before the tournament, all players were habituated to  
191 the measurements of countermovement jump (CMJ), wellbeing,  
192 the global positioning system (GPS), heart rate monitor and  
193 rating of perceived exertion scale (sRPE). On each day of the  
194 tournament, players arrived at the venue between 07:30 and  
195 09:00, at which point they completed two CMJs and a wellbeing  
196 questionnaire before completing matches as dictated by the  
197 schedule.

198

## 199 ***Procedures***

200

### 201 *Perceived wellbeing*

202

203 Away from team mates and coaches, players provided ratings of  
204 perceived fatigue, mood, muscle soreness, sleep quality and  
205 stress using a 1- to 5-point Likert scale. Higher values were  
206 indicative of a positive response to the question, with lower  
207 values representing a negative outcome (e.g. 1 = “very sore” to

208 5 = “feeling great”).

209

210 *Neuromuscular function*

211

212 Participants completed two CMJs with hands placed on hips in  
213 an upright position before flexing at the knee to a self-selected  
214 depth and extending into the jump for maximal height, keeping  
215 their legs straight throughout. A 60 s passive recovery was  
216 permitted between jumps. Jump height (CV = 8.3%), peak force  
217 (PF; CV = 5.4%) and peak power (PPO; CV = 4.7%) were  
218 recorded using a uni-axial calibrated force platform (HUR Labs,  
219 FP4, Tampere, Finland) sampling at 1200 Hz and analysed using  
220 custom software (HUR Labs Force Platform Software Suite).  
221 Jump height (cm) was automatically calculated from flight time  
222 whilst peak power output (W) was calculated using in-built  
223 equations.

224

225 *Measures of external and internal load*

226

227 Players wore the same 10 Hz microtechnology device (Optimeye  
228 S5, Catapult Innovations, Melbourne, Australia) for all matches,  
229 fitted into a custom-made vest positioned between the  
230 participant’s scapulae. All devices were activated for the warm  
231 up (40 minutes before the ‘tap-off’) to enable acquisition of  
232 satellite signals. Data were truncated manually by the lead  
233 researcher based on the velocity trace to ensure only time when  
234 players were on the field was used for analysis (Sprint, Version  
235 5.1, Catapult Sports, VIC, Australia). Measures of playing time,

236 absolute and relative total-, low- (<14 km·h<sup>-1</sup>) and high-intensity  
237 distance (>14 km·h<sup>-1</sup>), and time spent above high metabolic  
238 power (HMP; >20 W·kg<sup>-1</sup>) were determined.

239

240 Players also wore a heart rate monitor which transmitted to the  
241 GPS device continuously during all matches with mean (HR<sub>mean</sub>)  
242 heart rate calculated. Finally, 20 minutes after each match,  
243 participants provided a rating of perceived exertion using a 10-  
244 point scale, which was subsequently multiplied by playing  
245 duration (sRPE-TL).<sup>18</sup>

246

247 Statistical analysis

248

249 Within-sex changes were analysed using a post-only crossover  
250 spreadsheet.<sup>19</sup> Between-sex differences in the change in  
251 wellbeing and neuromuscular function were assessed using a  
252 pre-post parallel-groups spreadsheet<sup>20</sup> with day 1 scores used as  
253 a covariate to control for baseline imbalances between groups.

254 Data were analysed using effect sizes and 95% confidence limits  
255 (ES ± 95% CL), with threshold values of 0.0-0.2, *trivial*; 0.2-0.6,  
256 *small*; 0.6-1.2, *moderate*; 1.2-2.0, *large*; >2.0, *very large* used.

257 To supplement these effect sizes and 95%CL, inferences on the  
258 magnitude of difference/change included: 25-75% *possibly*, 75-  
259 95% *likely*, 95-99% *very likely* and > 99.5 *most likely*.<sup>21</sup> Effects  
260 with confidence limits that crossed a small positive or negative  
261 change were classified as *unclear*. To ascertain the association

262 between wellbeing and neuromuscular function with measures  
263 of workload, linear mixed models were constructed for each  
264 dependent variable (workload measure), with player included as  
265 a random factor, wellbeing and neuromuscular function  
266 measures included as fixed factors and day to account for the  
267 repeated measures (Supplement 1). To do this, scores from each  
268 morning were paired with the subsequent workload with all fixed  
269 factors entered into the model. Measures of neuromuscular  
270 function were grand-mean centered. The  $t$  statistic from all  
271 models was converted to an effect size correlation ( $\eta^2$ )<sup>22</sup> with  
272 95% CL. The size of the effect was interpreted as: <0.1, trivial;  
273 0.1-0.3, small; 0.3-0.5, moderate, 0.5-0.7, large; 0.7-0.9, very  
274 large; 0.9-0.99, almost perfect; 1, perfect. The likelihood of the  
275 effect was established using magnitude-based decisions with the  
276 following applied: <1% (almost certainly not), 1% to 5% (*very*  
277 *unlikely*), 5% to 25% (*unlikely*), 25% to 75% (*possibly*), 75% to  
278 97.5% (*likely*), 97.5% to 99% (*very likely*), and >99% (*almost*  
279 *certainly*).<sup>21</sup>

280

## 281 **Results**

282

### 283 ***Playing time***

284

285 No clear mean difference was observed for mean playing time  
286 on day 2 ( $0.12 \pm 0.68$ ) whilst mean playing time was *likely* ( $0.39$   
287  $\pm 0.29$ ) and *possibly* ( $0.24 \pm 0.19$ ) higher on day 3 and 4,  
288 respectively, compared to day 1. No clear mean difference was

289 observed in playing time for days 2 ( $-0.42 \pm 0.65$ ), 3 ( $-0.15 \pm$   
290  $0.59$ ) and 4 ( $0.07 \pm 0.69$ ) compared to day 1 for males.

### 291 ***Match loads***

292 Changes in the mean relative distance and relative low-intensity  
293 distance covered by females were *unclear* on day 2 ( $-0.10 \pm 0.53$ ;  
294  $-0.01 \pm 0.74$ ) and day 4 ( $-0.09 \pm 0.42$ ;  $0.05 \pm 0.64$ ), and *likely*  
295 lower on day 3 ( $-0.41 \pm 0.35$ ;  $-0.37 \pm 0.50$ ) when compared to  
296 day 1. Mean relative high-intensity distance was *possibly* and  
297 *likely* lower on days 2 ( $-0.28 \pm 0.40$ ) and 3 ( $-0.43 \pm 0.29$ ),  
298 respectively, but *unclear* on day 4 ( $-0.17 \pm 0.40$ ) when compared  
299 to day 1. For males, mean relative distance was *very likely* higher  
300 on day 2 ( $0.55 \pm 0.41$ ), *possibly* higher on day 3 ( $0.23 \pm 0.48$ )  
301 and *likely* higher on day 4 ( $0.46 \pm 0.44$ ) when compared to day  
302 1, whereas mean low-intensity distance was *very likely* higher on  
303 day 2 ( $0.63 \pm 0.45$ ) and *unclear* on day 3 ( $-0.01 \pm 0.51$ ) and 4  
304 ( $0.12 \pm 0.38$ ). Changes in mean relative high-intensity distance  
305 were *unclear* for day 2 ( $-0.83 \pm 0.1.40$ ) and 4 ( $0.08 \pm 0.94$ ), but  
306 *likely* lower on day 3 ( $-0.71 \pm 0.81$ ) when compared to day 1. No  
307 clear changes were observed in mean time spent above HMP for  
308 females across day 2 ( $-0.03 \pm 0.82$ ), 3 ( $-0.08 \pm 0.41$ ) and 4 ( $0.31$   
309  $\pm 0.59$ ). For males, the changes in HMP were *unclear* on day 2  
310 ( $0.18 \pm 0.69$ ), *likely* higher on day 3 ( $0.51 \pm 0.40$ ) and *most likely*  
311 higher on day 4 ( $0.99 \pm 0.44$ ) compared to day 1 (Table 1).

312 HR<sub>mean</sub> for the females was *likely* lower on day 2 ( $-0.47 \pm 0.48$ )

313 and 4 ( $-0.36 \pm 0.42$ ), and *very likely* lower on day 3 ( $-0.66 \pm 0.39$ )  
314 compared to day 1. For males,  $HR_{\text{mean}}$  was *possibly* higher on  
315 day 2 ( $0.17 \pm 0.33$ ) and *most likely* and *likely* lower on days 3 ( $-$   
316  $0.70 \pm 0.34$ ) and 4 ( $-0.74 \pm 0.70$ ), respectively. No clear within-  
317 sex change in mean sRPE-TL were observed for males for days  
318 1 ( $0.16 \pm 0.75$ ), 2 ( $0.24 \pm 0.65$ ) and 3 ( $0.43 \pm 0.80$ ), and females  
319 for days 2 ( $-0.04 \pm 0.74$ ) and 3 ( $-0.06 \pm 0.32$ ); a *likely* higher  
320 sRPE-TL was observed on day 4 ( $0.41 \pm 0.49$ ).

321 \*\*\*\* INSERT TABLE 1 ABOUT HERE \*\*\*\*

322

### 323 *Perceptual and Neuromuscular Fatigue Responses*

324

325 Within-sex changes in wellbeing are presented in Figure 1. No  
326 clear between-sex differences in the magnitude of change were  
327 observed for sleep (day 1-4;  $-0.39$  to  $0.11$ ), fatigue, stress,  
328 soreness (day 2;  $0.08$  to  $0.31$ ), and mood (day 4;  $0.11 \pm 0.50$ ).  
329 The reduction observed for fatigue, soreness and overall  
330 wellbeing were greater for females on days 3 ( $0.39 \pm 0.57$ ,  
331 *possibly*;  $0.62 \pm 0.71$ ; *likely*; and  $0.46 \pm 0.55$ ; *likely*, respectively)  
332 and 4 ( $0.78 \pm 0.72$ , *likely*;  $0.49 \pm 0.66$ , *likely*;  $0.61 \pm 0.64$ ).  
333 Perceptions of stress were also *likely* higher for females on days  
334 3 ( $0.46 \pm 0.50$ ) and 4 ( $0.68 \pm 0.61$ ), whilst mood was *likely* lower  
335 in males on day 2 ( $-0.60 \pm 0.70$ ) and females for day 3 ( $0.71 \pm$   
336  $0.71$ ).

337

338

339

340

\*\*\*\* INSERT FIGURE 1 ABOUT HERE \*\*\*\*

341 Within-sex changes in CMJ height, relative PPO and relative PF  
342 are presented in Figure 2. There was no between-sex difference  
343 in the change in CMJ height for day 2 ( $0.08 \pm 0.37$ ), but the  
344 decrement in CMJ height was *likely* higher for females on days  
345 3 ( $0.53 \pm 0.57$ ) and 4 ( $0.66 \pm 0.65$ ). A *likely* ( $0.37 \pm 0.45$ ), *very*  
346 *likely* ( $0.54 \pm 0.40$ ) and *possibly* ( $0.21 \pm 0.41$ ) greater decrease  
347 in relative PPO across days 2, 3 and 4, respectively, for females  
348 compared to males was observed. A *likely trivial* difference was  
349 observed in in relative PF between sexes on day 2 ( $0.09 \pm 0.25$ )  
350 but was unclear on day 3 ( $-0.04 \pm 0.25$ ) and 4 ( $0.02 \pm 0.28$ ).

351

352 \*\*\*\* INSERT FIGURE 2 ABOUT HERE \*\*\*\*

353

354

355 ***Association between well-being and neuromuscular function***  
356 ***with match loads.***

357

358 The association between total wellbeing score and measures of  
359 neuromuscular function with match loads across the tournament  
360 are presented in Figure 3. Our results indicated that wellbeing  
361 was negatively associated (*likely*) with high-intensity distance  
362 ( $\eta^2 = 0.15$ ) and time spent at HMP ( $\eta^2 = 0.21$ ), whilst PF was  
363 *likely to most likely* positively associated with relative ( $\eta^2 =$   
364  $0.39$ ), low and high-intensity ( $\eta^2 = 0.22$  and  $0.30$ ) distance, total  
365 high intensity distance ( $\eta^2 = 0.31$ ) and time at HMP ( $\eta^2 = 0.17$ ).  
366 CMJ height was positively (*likely to very likely*) associated with  
367 high intensity distance ( $\eta^2 = 0.24$ ), relative high-intensity

368 distance ( $\eta^2 = 0.16$ ) and HMP ( $\eta^2 = 0.18$ ), whilst association  
369 between CMJ PPO and match loads were largely unclear.

370 \*\*\*\* INSERT FIGURE 3 ABOUT HERE \*\*\*\*

371

## 372 **Discussion**

373

374 For the first time, we describe the wellbeing, neuromuscular  
375 responses and match loads over a 4-day international Touch  
376 tournament. Our results indicated that across a 4-day  
377 tournament, total wellbeing and neuromuscular function  
378 decreased, with greater decrements in fatigue, soreness, jump  
379 height and relative PPO in female Touch players. The internal,  
380 external and perceptual responses to competition fluctuated  
381 across the tournament for both males and females, with some  
382 measures of load lowest on day 3. Observed associations  
383 between wellbeing, CMJ height and CMJ PF with match activity  
384 supports the notion that impaired muscle function does, to some  
385 extent, influence running loads in Touch players. Taken  
386 together, these data suggest that across an international  
387 competition, elite Touch players experience neuromuscular  
388 fatigue and a reduction in wellbeing, particularly in females,  
389 which is associated with altered match running performance.

390

391 Mean playing time for males and females was similar to that  
392 observed in international female players by Marsh et al.,<sup>2</sup> but  
393 higher than that reported for male players by Beaven et al.<sup>1</sup> In  
394 agreement with Marsh et al.<sup>2</sup> females in this study reported a



395 *likely* lower relative total, lower-intensity and high-intensity  
396 distance on day 3, which might be influenced by perceptions of  
397 fatigue and soreness; albeit, associations were trivial. The  
398 consistently higher sRPE-TL reported by females is in  
399 agreement with Kellmann et al.'s observation that females  
400 reported a higher perceived load than males for a given external  
401 load; this might be explained by females' greater willingness to  
402 report how they perceived the load,<sup>23</sup> contextual factors such as  
403 opposition quality<sup>7</sup> as well as differences in training status.  
404 Males also reported the lowest relative high-intensity distances  
405 on day 3, yet were able to attain the highest relative total and  
406 high-intensity distance, time at HMP and sRPE-TL on day 4  
407 reflecting the greater opposition quality<sup>7</sup> and match importance  
408 (i.e. final). Interestingly, there was an overall reduction in  
409 HR<sub>mean</sub> in both males and females across the tournament,  
410 agreeing with the findings of Hogarth et al.,<sup>24</sup> who observed  
411 similar reductions in HR during five successive tag rugby  
412 matches. These observations possibly reflect players' changes in  
413 pacing strategy during a match, whereby they adopt a greater of  
414 number of self-selected interchanges and adjust their running  
415 activity as the tournament progresses to accommodate the  
416 accumulated fatigue and muscle damage, whilst ensuring that  
417 they are able to meet the demands of the match (e.g. complete  
418 sufficient high-intensity running). Indeed, the observation that  
419 high-intensity running declined on day 3 before increasing on

420 day 4, often described as the ‘end-spurt phenomenon’, provides  
421 further evidence that Touch players adopt a pacing strategy  
422 during tournaments.<sup>25</sup> Further work is required to confirm this  
423 proposition as well as other possible mechanisms, such as hyper-  
424 activation of the parasympathetic nervous system in response to  
425 non-functional overreaching.<sup>26</sup>

426

427 Changes in perceived wellbeing during the tournament were  
428 consistent with previous studies of intensified competition  
429 periods.<sup>7,9</sup> We observed a small reduction in total wellbeing  
430 across days 2 to 4. However, much of the change in total  
431 wellbeing was accounted for by the small to very large changes  
432 in perceived fatigue and muscle soreness. These findings are  
433 likely caused by the high-intensity running and time above high  
434 metabolic power as well as the need to repeat these actions  
435 during 5-6 matches over the first two days of competition.<sup>27</sup>  
436 Between-sex analysis revealed no clear differences on day 2,  
437 though females did appear to report greater reductions in fatigue,  
438 soreness and total wellbeing compared to males on day 3 and 4.  
439 When compared to males, female basketball players reported  
440 lower values for physical recovery, sleep quality and self-  
441 efficacy using the recovery/stress questionnaire for sport.<sup>28</sup>  
442 Further, female rowers reported higher scores for stress-related  
443 RESTQ-sport and lower values for recovery when compared to  
444 elite junior male rowers despite no significant differences in

445 training load.<sup>23</sup> Therefore, the consistently higher sRPE-TL  
446 reported by females in our study might explain the impaired  
447 perceived recovery compared to males,<sup>23,28</sup> despite a lower mean  
448 relative distance, high-intensity distance and time spent above  
449 HMP. Associations between wellbeing and match-related  
450 running performance revealed a small-to-moderate positive  
451 relationship for playing time, HR<sub>mean</sub>, and sRPE-TL in females  
452 whilst males only demonstrated a small positive association with  
453 playing time. Small-to-moderate negative associations were  
454 observed between wellbeing and relative total and high-intensity  
455 distance and time above HMP in males; albeit match-to-match  
456 variation and opposition quality during the tournament as well  
457 as the influence of the ‘pod system’ used in Touch, whereby two  
458 or three players of the same position self-interchange during a  
459 match, requires consideration. Taken together, these data  
460 indicate that player sex should to be taken into account when  
461 managing perceived wellbeing during an international Touch  
462 tournament, and effective strategies to minimise decrements in  
463 running performance require consideration.

464

465 Small-to-moderate reductions in CMJ height and relative PPO  
466 were observed over days 2 to 4 in both males and females when  
467 compared to day 1. These findings are consistent with previous  
468 research that has observed decrements in neuromuscular  
469 function across intensified periods of team sport activity<sup>4,29</sup>

470 Changes in PF were *likely trivial* and reaffirm previous findings  
471 that measures of muscle force might lack sensitivity.<sup>29</sup> This  
472 observation is likely explained by the preferential damage to  
473 type II muscle fibres resulting from the high-intensity  
474 intermittent, multidirectional running demands and accumulated  
475 load.<sup>30</sup> Such changes will alter the force-velocity relationship  
476 and could compromise a player's ability to execute velocity-  
477 dominant actions. Between-sex differences were observed for  
478 the change in CMJ flight time and power on days 3 and 4 with  
479 *likely trivial* differences observed for PF. While an  
480 understanding of between sex-differences in muscle function  
481 after muscle damaging exercise remain equivocal,<sup>13,14,31</sup> we  
482 propose the greater loss in jump height and relative PPO for  
483 females in this study might be explained by higher perceived  
484 soreness and fatigue and greater perceived loads compared to  
485 males. A higher perceived soreness is likely to reduce voluntary  
486 activation, which has been reported after damaging exercise<sup>13</sup>  
487 and might contribute to a lower jump performance in females as  
488 the tournament progressed. In addition, the higher metabolic  
489 load for females, as evidenced by the higher heart rate, coupled  
490 with the potential for poor energy intake previously reported in  
491 female Touch players during a tournament<sup>2</sup> might have resulted  
492 in a greater glycogen depletion from successive matches that  
493 manifest as a greater reduction in muscle function.<sup>32</sup> These  
494 suggestions are despite the trivial-to-moderate relationships

495 between measures of neuromuscular function (i.e. CMJ height  
496 and PPO) and responses to match-play. The reductions in jump  
497 height and relative PPO over the course of the tournament  
498 suggests careful management of players is needed by  
499 practitioners and coaches using appropriate tactical, recovery  
500 and nutritional strategies, with particular attention given to  
501 female players.

502

503 Whilst this study is the first to present changes in wellbeing,  
504 neuromuscular function and match load across an international  
505 Touch tournament, there are several limitations that warrant  
506 discussion. The findings represent three individual (men's,  
507 women's and mixed open) teams from a single nation from  
508 which the data were pooled and reported by sex. Our data do not  
509 therefore represent those of specific teams. It is also important to  
510 consider the tactical and technical aspects of the game given the  
511 influence factors such as pod number (i.e. 2 or 3 players rotating  
512 as interchanges) might have on wellbeing, neuromuscular and  
513 match responses. However, such information is difficult to  
514 access and account for within the analysis. Within this study we  
515 are unable to comment on the mechanistic origins of the fatigue  
516 and EIMD (e.g. voluntary activation, biochemical, hormonal,  
517 inflammatory) due to the applied nature of this study. Finally,  
518 several *possible* and *unclear* effects were observed in our study  
519 and therefore replication studies are warranted.

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522 **Practical applications**

523 During international Touch competition, coaches and sport  
524 scientists should monitor a player's wellbeing and  
525 neuromuscular function and manage responses accordingly,  
526 particularly those working with female Touch players.  
527 Furthermore, practitioners and coaches should strive to manage  
528 workload appropriately through rest or implementing tactical  
529 changes such as changing from a '2-pod' (i.e. work to rest ratio  
530 of 1:1) to '3-pod' (work to rest ratio of 1:2) system as well as  
531 considering effective recovery and nutritional strategies between  
532 matches and days. Finally, administrators organising Touch  
533 competitions, might consider organising fixtures in a way that  
534 provides players with sufficient recovery on day 3 where players  
535 appear most fatigued and likely to be susceptible to fatigue-  
536 related injuries.

537

538 **Conclusions**

539 We observed reductions in wellbeing, CMJ height and PPO in  
540 male and female Touch players during an international Touch  
541 tournament, with greater reductions observed in females during  
542 the latter stages of the tournament compared to males. Changes  
543 in match-play loads varied across each of the four days with a  
544 reduction on day 3 but higher running speeds on the final day.

545 While 9-10 Touch matches over a 4-day period has detrimental  
546 effects on wellbeing and neuromuscular function, players  
547 seemingly adopt a match pacing strategy as the tournament  
548 progresses that enables the highest exercise intensities on the  
549 final day. These data can be used by practitioners and coaches to  
550 develop appropriate support strategies and tactical approaches to  
551 ensure Touch players are prepared for the rigours of intensified  
552 tournament competition.

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Table 1. Mean external, internal and perceptual loads of 2-3 matches presented per day across an international 4-day touch rugby tournament.

		Competition Day			
		1	2	3	4
Playing time (min)	Females	20.6 ± 9.2	21.9 ± 9.7 <sup>t</sup>	22.3 ± 7.0 <sup>s**</sup>	21.9 ± 7.3 <sup>s*</sup>
	Males	19.5 ± 8.1	18.5 ± 6.1 <sup>s</sup>	19.3 ± 6.0 <sup>t</sup>	19.7 ± 6.0 <sup>t</sup>
Total distance (m)	Females	2393 ± 782	2606 ± 1001 <sup>s</sup>	2507 ± 717 <sup>s**</sup>	2573 ± 707 <sup>s**</sup>
	Males	2350 ± 912	2436 ± 526 <sup>s</sup>	2402 ± 551 <sup>t</sup>	2572 ± 566 <sup>t</sup>
Total distance (m·min <sup>-1</sup> )	Females	122.7 ± 21.2	121.1 ± 16.6 <sup>t</sup>	114.7 ± 11.0 <sup>s**</sup>	121.0 ± 13.6 <sup>t</sup>
	Males	123.3 ± 17.8	134.8 ± 14.0 <sup>s***</sup>	128.1 ± 15.7 <sup>s</sup>	133.7 ± 11.8 <sup>s**</sup>
Low-intensity distance (m)	Females	2011 ± 811	2207 ± 1018 <sup>s</sup>	2147 ± 776 <sup>s**</sup>	2178 ± 721 <sup>s**</sup>
	Males	1981 ± 1101	1981 ± 784 <sup>t</sup>	1804 ± 489 <sup>t</sup>	1919 ± 562 <sup>t</sup>
Low-intensity distance (m·min <sup>-1</sup> )	Females	100.2 ± 11.1	100.7 ± 13.8 <sup>t</sup>	96.2 ± 7.9 <sup>s**</sup>	100.7 ± 7.9 <sup>t</sup>
	Males	97.3 ± 13.9	105.7 ± 8.2 <sup>m***</sup>	95.7 ± 13.8 <sup>t</sup>	97.9 ± 9.3 <sup>t</sup>
High-intensity distance (m)	Females	383 ± 128	371 ± 123 <sup>t</sup>	371 ± 122 <sup>t</sup>	385 ± 141 <sup>t</sup>
	Males	477 ± 150	526 ± 169 <sup>t</sup>	568 ± 133 <sup>m**</sup>	621 ± 118 <sup>m**</sup>
High-intensity distance (m·min <sup>-1</sup> )	Females	22.9 ± 13.2	19.1 ± 9.1 <sup>s*</sup>	17.9 ± 7.7 <sup>s**</sup>	21.0 ± 11.5 <sup>t</sup>
	Males	32.5 ± 6.4	31.2 ± 9.7 <sup>m</sup>	30.6 ± 8.0 <sup>m**</sup>	35.3 ± 7.8 <sup>t</sup>
Time spent above HMP (min:s)	Females	1:50 ± 0:24	1:49 ± 0:27 <sup>t</sup>	1:48 ± 0:28 <sup>t</sup>	2:00 ± 0:30 <sup>s</sup>
	Males	2:00 ± 0:28	2:10 ± 0:33 <sup>t</sup>	2:12 ± 0:24 <sup>s**</sup>	2:30 ± 0:20 <sup>m****</sup>
Mean HR (b·min <sup>-1</sup> )	Females	144 ± 14	137 ± 20 <sup>s**</sup>	135 ± 21 <sup>m***</sup>	137 ± 14 <sup>s**</sup>
	Males	126 ± 13	130 ± 15 <sup>t*</sup>	117 ± 16 <sup>m****</sup>	114 ± 22 <sup>m**</sup>
sRPE-TL (AU)	Females	108 ± 59	105 ± 67 <sup>t</sup>	101 ± 58 <sup>t</sup>	129 ± 59 <sup>s**</sup>
	Males	73 ± 38	96 ± 38 <sup>t</sup>	80 ± 45 <sup>s</sup>	97 ± 38 <sup>s</sup>

Data presented as mean ± SD. <sup>t</sup>= trivial, <sup>s</sup>= small, <sup>m</sup>= moderate within-sex effect size compared to day 1. \* *possibly*, \*\* *likely*, \*\*\* *very likely*, \*\*\*\* *most likely*. HMP = high metabolic power (> 20 W·kg<sup>-1</sup>). HR = heart rate. sRPE-TL = perceived load.

Figure 1. Mean  $\pm$  SD for perceived fatigue, sleep, muscle soreness, stress, mood and total score for males (black solid line) and females (grey dashed line) across the tournament. Descriptors and effect sizes for male (black text) and females (grey text) are compared to day 1.

Figure 2. Mean  $\pm$  SD for jump height (top), peak power (middle) and PF (bottom) for males (black solid line) and females (grey dashed line) across the tournament. Descriptors and effect sizes for male (black text) and females (grey text) are compared to day 1.

Figure 3. Effect size correlations (95% confidence intervals, CI) between well-being (circle), CMJ peak power (triangles), CMJ height (diamond) and CMJ PF (squares) with measures of external, internal and perceptual load across the four-day tournament. \* *Possibly*, \*\* *likely*, \*\*\* *very likely*, \*\*\*\* *most likely*.