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Dobbin, Nick , Thorpe, Cari, Highton, Jamie and Twist, Cari (2020) Sex-related changes in physical performance, wellbeing and neuromuscular function of elite Touch players during a 4-day international tournament. *International Journal of Sports Physiology and Performance*, 15 (8). pp. 1138-1146. ISSN 1555-0273

DOI: <https://doi.org/10.1123/ijsp.2019-0594>

Publisher: Human Kinetics

Version: Accepted Version

Downloaded from: <https://e-space.mmu.ac.uk/624515/>

Additional Information: This is an Author Accepted Manuscript of a paper accepted for publication by Human Kinetics in *International Journal of Sports Physiology and Performance*

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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 (η^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.¹⁻³ 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^{1,3} and
87 one across an entire tournament.² 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 ± 5.50 minutes.¹ 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.¹ 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 $96.9 \text{ m}\cdot\text{min}^{-1}$).² Furthermore, Marsh et al.² 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.⁴ 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.⁵

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 performance⁵⁻⁷ 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.⁶ 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.⁸ 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).⁵ Nonetheless, Hogarth et al.⁷ 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.⁶
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.⁹ For
147 example, Hunter¹⁰ 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 sexes¹¹⁻¹⁵ or greater losses for females
155 compared to males.¹⁶ 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,^{9,13,16} and repeated sprint exercise,¹⁷ 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 ± 5.4 y,
178 mass = 75.8 ± 8.0 kg, stature = 176.9 ± 5.7 cm) and 20 female
179 (age = 26.4 ± 5.6 y, mass = 60.1 ± 6.2 kg, stature = 163.3 ± 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⁻¹) and high-intensity
237 distance (>14 km·h⁻¹), and time spent above high metabolic
238 power (HMP; >20 W·kg⁻¹) 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_{mean})
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).¹⁸

246

247 Statistical analysis

248

249 Within-sex changes were analysed using a post-only crossover
250 spreadsheet.¹⁹ Between-sex differences in the change in
251 wellbeing and neuromuscular function were assessed using a
252 pre-post parallel-groups spreadsheet²⁰ 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*.²¹ 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 (η^2)²² 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*).²¹

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 ± 0.68) whilst mean playing time was *likely* (0.39
287 ± 0.29) and *possibly* (0.24 ± 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 ± 0.65), 3 ($-0.15 \pm$
290 0.59) and 4 (0.07 ± 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 ± 0.53 ;
294 -0.01 ± 0.74) and day 4 (-0.09 ± 0.42 ; 0.05 ± 0.64), and *likely*
295 lower on day 3 (-0.41 ± 0.35 ; -0.37 ± 0.50) when compared to
296 day 1. Mean relative high-intensity distance was *possibly* and
297 *likely* lower on days 2 (-0.28 ± 0.40) and 3 (-0.43 ± 0.29),
298 respectively, but *unclear* on day 4 (-0.17 ± 0.40) when compared
299 to day 1. For males, mean relative distance was *very likely* higher
300 on day 2 (0.55 ± 0.41), *possibly* higher on day 3 (0.23 ± 0.48)
301 and *likely* higher on day 4 (0.46 ± 0.44) when compared to day
302 1, whereas mean low-intensity distance was *very likely* higher on
303 day 2 (0.63 ± 0.45) and *unclear* on day 3 (-0.01 ± 0.51) and 4
304 (0.12 ± 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 ± 0.94), but
306 *likely* lower on day 3 (-0.71 ± 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 ± 0.82), 3 (-0.08 ± 0.41) and 4 (0.31
309 ± 0.59). For males, the changes in HMP were *unclear* on day 2
310 (0.18 ± 0.69), *likely* higher on day 3 (0.51 ± 0.40) and *most likely*
311 higher on day 4 (0.99 ± 0.44) compared to day 1 (Table 1).

312 HR_{mean} for the females was *likely* lower on day 2 (-0.47 ± 0.48)

313 and 4 (-0.36 ± 0.42), and *very likely* lower on day 3 (-0.66 ± 0.39)
314 compared to day 1. For males, HR_{mean} was *possibly* higher on
315 day 2 (0.17 ± 0.33) and *most likely* and *likely* lower on days 3 ($-$
316 0.70 ± 0.34) and 4 (-0.74 ± 0.70), respectively. No clear within-
317 sex change in mean sRPE-TL were observed for males for days
318 1 (0.16 ± 0.75), 2 (0.24 ± 0.65) and 3 (0.43 ± 0.80), and females
319 for days 2 (-0.04 ± 0.74) and 3 (-0.06 ± 0.32); a *likely* higher
320 sRPE-TL was observed on day 4 (0.41 ± 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 ± 0.50).
329 The reduction observed for fatigue, soreness and overall
330 wellbeing were greater for females on days 3 (0.39 ± 0.57 ,
331 *possibly*; 0.62 ± 0.71 ; *likely*; and 0.46 ± 0.55 ; *likely*, respectively)
332 and 4 (0.78 ± 0.72 , *likely*; 0.49 ± 0.66 , *likely*; 0.61 ± 0.64).
333 Perceptions of stress were also *likely* higher for females on days
334 3 (0.46 ± 0.50) and 4 (0.68 ± 0.61), whilst mood was *likely* lower
335 in males on day 2 (-0.60 ± 0.70) and females for day 3 ($0.71 \pm$
336 0.71).

337

338 **** INSERT FIGURE 1 ABOUT HERE ****

339

340

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 ± 0.37), but the
344 decrement in CMJ height was *likely* higher for females on days
345 3 (0.53 ± 0.57) and 4 (0.66 ± 0.65). A *likely* (0.37 ± 0.45), *very*
346 *likely* (0.54 ± 0.40) and *possibly* (0.21 ± 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 ± 0.25)
350 but was unclear on day 3 (-0.04 ± 0.25) and 4 (0.02 ± 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.,² but
393 higher than that reported for male players by Beaven et al.¹ In
394 agreement with Marsh et al.² 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,²³ contextual factors such as
403 opposition quality⁷ 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 quality⁷ and match importance
408 (i.e. final). Interestingly, there was an overall reduction in
409 HR_{mean} in both males and females across the tournament,
410 agreeing with the findings of Hogarth et al.,²⁴ 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.²⁵ 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.²⁶

426

427 Changes in perceived wellbeing during the tournament were
428 consistent with previous studies of intensified competition
429 periods.^{7,9} 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.²⁷
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.²⁸
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.²³ Therefore, the consistently higher sRPE-TL
446 reported by females in our study might explain the impaired
447 perceived recovery compared to males,^{23,28} 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_{mean}, 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^{4,29}

470 Changes in PF were *likely trivial* and reaffirm previous findings
471 that measures of muscle force might lack sensitivity.²⁹ 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.³⁰ 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,^{13,14,31} 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 exercise¹³
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 tournament² might have resulted
492 in a greater glycogen depletion from successive matches that
493 manifest as a greater reduction in muscle function.³² 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.

520

521

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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567 **Acknowledgment**

568 The authors would like to thank the Sam Griffith for his
569 assistance with data collection and the continued support from

570 players and coaches at England Touch Association. We would
571 also like to thank Catapult Sports for supporting this research
572 through the provision of GPS units.

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

Data presented as mean ± SD. ^t= trivial, ^s= small, ^m= moderate within-sex effect size compared to day 1. * *possibly*, ** *likely*, *** *very likely*, **** *most likely*. HMP = high metabolic power (> 20 W·kg⁻¹). 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*.