Sex-related changes in physical performance, wellbeing and neuromuscular function of elite Touch players during a four-day international tournament.

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

Abstract

Purpose: To examine the within- and between-sex physical performance, wellbeing and neuromuscular function responses across a four-day international touch rugby (Touch) tournament. ***Methods:*** Twenty females and twenty-one males completed measures of wellbeing (fatigue, soreness, sleep, mood, stress) and neuromuscular function (countermovement jump (CMJ) height, peak power output (PPO) and peak force (PF)) during a 4-day tournament with internal, external and perceptual loads recorded for all matches. ***Results:*** Relative and absolute total, low- (*females*) and high-intensity distance was lower on day 3 (*males and females*) (ES = -0.37 to -0.71) compared to day 1. Mean heart rate was *possibly* to *most likely* reduced during the tournament (except day 2 males) (ES = -0.36 to -0.74), whilst RPE-TL was consistently higher in females (ES = 0.02 to 0.83). The change in mean fatigue, soreness and overall wellbeing were *unclear* to *most likely* lower (ES = -0.33 to -1.90) across the tournament for both sexes, with greater perceived fatigue and soreness in females on days 3-4 (ES = 0.39 to 0.78). Jump height and PPO were *possibly* to *most likely* lower across days 2-4 (ES = -0.30 to -0.84), with greater reductions in females (ES = 0.21 to 0.66). Wellbeing, CMJ height, and PF were associated with changes in external, internal and perceptual measures of load across the tournament (η^2 = -0.37 to 0.39). ***Conclusions:*** Elite Touch players experience reductions in wellbeing,

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

Introduction

Touch rugby (Touch) is an intermittent team sport that is played globally at regional, national and international standards, and is characterised by frequent periods of high-intensity activity interspersed with periods of passive recovery during interchanges.[1-3] The use of microtechnology that incorporates a global positioning system and accelerometer have been used extensively in team sports, though limited studies have documented the internal and external demands of Touch, with research limited to single-sex teams, using a single match[1,3] and one across an entire tournament .[2] For a single match, it was reported that international male players perform ~9 bouts of activity each lasting approximately 148 seconds, resulting in a mean playing time of 16.52 ± 5.50 minutes.[1] During this time, players cover mean total, low-intensity (< 14 $km \cdot h^{-1}$), high-intensity (> 14 $km \cdot h^{-1}$) and very high-intensity (> 20 $km \cdot h^{-1}$) distances of 2266 ± 594 m (137 ± 13.6 $m \cdot min^{-1}$), 1651 ± 594 m (98.2 ± 6.4 $m \cdot min^{-1}$), 620 ± 155 m (39.3 ± 12.0 $m \cdot min^{-1}$) and 119 ± 60 m (7.67 ± 4.40 $m \cdot min^{-1}$), respectively.[1] During the course of an international competition, female players competed in 9-10 matches over four consecutive days with high-intensity distance (i.e. match 1 = 29.3 ± 14.8 $m \cdot min^{-1}$) greatest on day one but progressively declining by day three (i.e. match 7 = 18.2 ± 96.9 $m \cdot min^{-1}$).[2] Furthermore, Marsh et al.[2] reported on the change in time spent at high metabolic power (20 $W \cdot kg^{-1}$), which was reduced on day three compared to day one. The use of high metabolic power, alongside more traditional measures of movement, offers a more comprehensive appraisal of the load imposed on athletes where multiple directional changes are involved.[4] Research using a range of movement characteristics is warranted to report the loads imposed on elite Touch players of both sexes during a tournament and to what extent the these loads change in subsequent matches.[5]

International Touch players typically compete in a tournament-style competition that comprises multiple matches over a three- or four-day period. The neuromuscular, physiological and cognitive perturbations associated with team sport athletes involved in congested fixtures is of interest given the potential negative impact on players' wellbeing and physical performance[5-7] as well as potential for increased injury risk. During a two-day international rugby sevens competition where female players competed in 4-6 matches, perceived wellbeing decreased substantially with players reporting greater muscle soreness at the end of the tournament.[6] During a junior rugby league tournament where players performed in five matches over a five-day period, a progressive decrease in wellbeing and neuromuscular function was observed, which was negatively associated with several performance variables including relative distance, high-speed running and number of repeated high-intensity efforts.[8] It is important to note that rugby sevens and rugby league both involve contact, which will likely influence measures of fatigue and exercise-induced muscle damage (EIMD).[5] Nonetheless, Hogarth et al.[7] reported a progressive decrease in wellbeing, while changes in jump height were unclear during a tag rugby competition that required male players to compete in three matches interspersed with 90-minutes recovery. The authors also reported that increased neuromuscular and perceptual fatigue over consecutive matches were associated with reductions in match running performance.[6] Further work is required to elucidate changes in wellbeing and neuromuscular function over the course of a Touch tournament, as well as the influence of any changes on match running performance.

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

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

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

Methods

Participants and design

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

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

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

Procedures

Perceived wellbeing

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

5 = “feeling great”).

Neuromuscular function

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

Measures of external and internal load

Players wore the same 10 Hz microtechnology device (Optimeye S5, Catapult Innovations, Melbourne, Australia) for all matches, fitted into a custom-made vest positioned between the participant’s scapulae. All devices were activated for the warm up (40 minutes before the ‘tap-off’) to enable acquisition of satellite signals. Data were truncated manually by the lead researcher based on the velocity trace to ensure only time when players were on the field was used for analysis (Sprint, Version 5.1, Catapult Sports, VIC, Australia). Measures of playing time, absolute and relative total-, low- (<14 km·h^{-1}) and high-intensity distance (>14 km·h^{-1}), and time spent above high metabolic power (HMP; >20 W·kg^{-1}) were determined.

Players also wore a heart rate monitor which transmitted to the GPS device continuously during all matches with mean (HR_{mean}) heart rate calculated. Finally, 20 minutes after each match, participants provided a rating of perceived exertion using a 10-point scale, which was subsequently multiplied by playing duration (sRPE-TL).[18]

Statistical analysis

Within-sex changes were analysed using a post-only crossover spreadsheet.[19] Between-sex differences in the change in wellbeing and neuromuscular function were assessed using a pre-post parallel-groups spreadsheet[20] with day 1 scores used as a covariate to control for baseline imbalances between groups. Data were analysed using effect sizes and 95% confidence limits (ES ± 95% CL), with threshold values of 0.0-0.2, *trivial*; 0.2-0.6, *small*; 0.6-1.2, *moderate*; 1.2-2.0, *large*; >2.0, *very large* used. To supplement these effect sizes and 95%CL, inferences on the magnitude of difference/change included: 25-75% *possibly*, 75-95% *likely*, 95-99% *very likely* and > 99.5 *most likely*.[21] Effects with confidence limits that crossed a small positive or negative change were classified as *unclear*. To ascertain the association between wellbeing and neuromuscular function with measures of workload, linear mixed models were constructed for each dependent variable (workload measure), with player included as a random factor, wellbeing and neuromuscular function measures included as fixed factors and day to account for the repeated measures (Supplement 1). To do this, scores from each morning were paired with the subsequent workload with all fixed factors entered into the model. Measures of neuromuscular function were grand-mean centered. The *t* statistic from all models was converted to an effect size correlation (η^2)[22] with 95% CL. The size of the effect was interpreted as: <0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate, 0.5-0.7, large; 0.7-0.9, very large; 0.9-0.99, almost perfect; 1, perfect. The likelihood of the effect was established using magnitude-based decisions with the following applied: <1% (almost certainly not), 1% to 5% (*very unlikely*), 5% to 25% (*unlikely*), 25% to 75% (*possibly*), 75% to 97.5% (*likely*), 97.5% to 99% (*very likely*), and >99% (*almost certainly*).[21]

Results

Playing time

No clear mean difference was observed for mean playing time on day 2 (0.12 ± 0.68) whilst mean playing time was *likely* (0.39 ± 0.29) and *possibly* (0.24 ± 0.19) higher on day 3 and 4, respectively, compared to day 1. No clear mean difference was observed in playing time for days 2 (-0.42 ± 0.65), 3 (-0.15 ± 0.59) and 4 (0.07 ± 0.69) compared to day 1 for males.

Match loads

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

HR_{mean} for the females was *likely* lower on day 2 (-0.47 ± 0.48) and 4 (-0.36 ± 0.42), and *very likely* lower on day 3 (-0.66 ± 0.39) compared to day 1. For males, HR_{mean} was *possibly* higher on day 2 (0.17 ± 0.33) and *most likely* and *likely* lower on days 3 (-0.70 ± 0.34) and 4 (-0.74 ± 0.70), respectively. No clear within-sex change in mean sRPE-TL were observed for males for days 1 (0.16 ± 0.75), 2 (0.24 ± 0.65) and 3 (0.43 ± 0.80), and females for days 2 (-0.04 ± 0.74) and 3 (-0.06 ± 0.32); a *likely* higher sRPE-TL was observed on day 4 (0.41 ± 0.49).

**** INSERT TABLE 1 ABOUT HERE ****

Perceptual and Neuromuscular Fatigue Responses

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

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

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

**** INSERT FIGURE 2 ABOUT HERE ****

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

The association between total wellbeing score and measures of neuromuscular function with match loads across the tournament are presented in Figure 3. Our results indicated that wellbeing was negatively associated (*likely*) with high-intensity distance (η^2 = 0.15) and time spent at HMP (η^2 = 0.21), whilst PF was *likely* to *most likely* positively associated with relative (η^2 = 0.39), low and high-intensity (η^2 = 0.22 and 0.30) distance, total high intensity distance (η^2 = 0.31) and time at HMP (η^2 = 0.17). CMJ height was positively (*likely* to *very likely*) associated with high intensity distance (η^2 = 0.24), relative high-intensity distance (η^2 = 0.16) and HMP (η^2 = 0.18), whilst association between CMJ PPO and match loads were largely unclear.

**** INSERT FIGURE 3 ABOUT HERE ****

Discussion

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

Mean playing time for males and females was similar to that observed in international female players by Marsh et al.,[2] but higher than that reported for male players by Beaven et al.[1] In agreement with Marsh et al.[2] females in this study reported a *likely* lower relative total, lower-intensity and high-intensity distance on day 3, which might be influenced by perceptions of fatigue and soreness; albeit, associations were trivial. The consistently higher sRPE-TL reported by females is in agreement with Kellmann et al.'s observation that females reported a higher perceived load than males for a given external load; this might be explained by females' greater willingness to report how they perceived the load,[23] contextual factors such as opposition quality[7] as well as differences in training status. Males also reported the lowest relative high-intensity distances on day 3, yet were able to attain the highest relative total and high-intensity distance, time at HMP and sRPE-TL on day 4 reflecting the greater opposition quality[7] and match importance (i.e. final). Interestingly, there was an overall reduction in HR_{mean} in both males and females across the tournament, agreeing with the findings of Hogarth et al.,[24] who observed similar reductions in HR during five successive tag rugby matches. These observations possibly reflect players' changes in pacing strategy during a match, whereby they adopt a greater of number of self-selected interchanges and adjust their running activity as the tournament progresses to accommodate the accumulated fatigue and muscle damage, whilst ensuring that they are able to meet the demands of the match (e.g. complete sufficient high-intensity running). Indeed, the observation that high-intensity running declined on day 3 before increasing on day 4, often described as the ‘end-spurt phenomenon’, provides further evidence that Touch players adopt a pacing strategy during tournaments.[25] Further work is required to confirm this proposition as well as other possible mechanisms, such as hyper-activation of the parasympathetic nervous system in response to non-functional overreaching.[26]

Changes in perceived wellbeing during the tournament were consistent with previous studies of intensified competition periods.[7,9] We observed a small reduction in total wellbeing across days 2 to 4. However, much of the change in total wellbeing was accounted for by the small to very large changes in perceived fatigue and muscle soreness. These findings are likely caused by the high-intensity running and time above high metabolic power as well as the need to repeat these actions during 5-6 matches over the first two days of competition.[27] Between-sex analysis revealed no clear differences on day 2, though females did appear to report greater reductions in fatigue, soreness and total wellbeing compared to males on day 3 and 4. When compared to males, female basketball players reported lower values for physical recovery, sleep quality and self-efficacy using the recovery/stress questionnaire for sport.[28] Further, female rowers reported higher scores for stress-related RESTQ-sport and lower values for recovery when compared to elite junior male rowers despite no significant differences in training load.[23] Therefore, the consistently higher sRPE-TL reported by females in our study might explain the impaired perceived recovery compared to males,[23,28] despite a lower mean relative distance, high-intensity distance and time spent above HMP. Associations between wellbeing and match-related running performance revealed a small-to-moderate positive relationship for playing time, HR_{mean}, and sRPE-TL in females whilst males only demonstrated a small positive association with playing time. Small-to-moderate negative associations were observed between wellbeing and relative total and high-intensity distance and time above HMP in males; albeit match-to-match variation and opposition quality during the tournament as well as the influence of the 'pod system' used in Touch, whereby two or three players of the same position self-interchange during a match, requires consideration. Taken together, these data indicate that player sex should to be taken into account when managing perceived wellbeing during an international Touch tournament, and effective strategies to minimise decrements in running performance require consideration.

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

Changes in PF were *likely trivial* and reaffirm previous findings that measures of muscle force might lack sensitivity.[29] This observation is likely explained by the preferential damage to type II muscle fibres resulting from the high-intensity intermittent, multidirectional running demands and accumulated load.[30] Such changes will alter the force-velocity relationship and could compromise a player's ability to execute velocity-dominant actions. Between-sex differences were observed for the change in CMJ flight time and power on days 3 and 4 with *likely trivial* differences observed for PF. While an understanding of between sex-differences in muscle function after muscle damaging exercise remain equivocal,[13,14,31] we propose the greater loss in jump height and relative PPO for females in this study might be explained by higher perceived soreness and fatigue and greater perceived loads compared to males. A higher perceived soreness is likely to reduce voluntary activation, which has been reported after damaging exercise[13] and might contribute to a lower jump performance in females as the tournament progressed. In addition, the higher metabolic load for females, as evidenced by the higher heart rate, coupled with the potential for poor energy intake previously reported in female Touch players during a tournament[2] might have resulted in a greater glycogen depletion from successive matches that manifest as a greater reduction in muscle function.[32] These suggestions are despite the trivial-to-moderate relationships between measures of neuromuscular function (i.e. CMJ height and PPO) and responses to match-play. The reductions in jump height and relative PPO over the course of the tournament suggests careful management of players is needed by practitioners and coaches using appropriate tactical, recovery and nutritional strategies, with particular attention given to female players.

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

Practical applications

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

Conclusions

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

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

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References

1. Beaven RP, Highton JM, Thorpe MC, et al. Movement and physiological demands of international and regional men’s touch rugby matches. *J Strength Cond Res.* 2014;28(11):3274-3279.

2. Marsh N, Dobbin N, Twist C, et al. Estimates of energy intake and expenditure in elite female touch players during an international tournament. *Int J Sport Nutr Exerc Metab.* 2017;27(6):499-506.
3. Vickery W, Harkness A. Physical, physiological and perceptual match demands of amateur mixed gender touch players. *J Sports Sci Med.* 2017;16(4):589-594.
4. Oxendale CL, Highton J, Twist, C. Energy expenditure, metabolic power and high speed activity during linear and multi-directional running. *J Sci Med Sport.* 2017; 20(10):957-961.
5. Twist C, Highton J, Daniels M, et al. Player responses to match and training demands during an intensified fixture schedule in professional rugby league: a case study. *Int J Sports Physiol Perform.* 2017;12(8):1093-1099.
6. Clarke AC, Anson JM, Pyne DB. Neuromuscular fatigue and muscle damage after a women's rugby sevens tournament. *Int J Sports Physiol Perform.* 2015;10(6):808-814.
7. Hogarth LW, Burkett BJ, McKean MR. Neuromuscular and perceptual fatigue responses to consecutive tag football matches. *Int J Sports Physiol Perform.* 2015; 10(5):559-565.
8. Johnston RD, Gabbett TJ, Jenkins D. Influence of an intensified competition on fatigue and match performance in junior rugby league players. *J Sci Med Sport.* 2013;16:460-465.
9. Hunter SK. The relevance of sex differences in performance fatigability. *Med Sci Sports Exerc.* 2016;48(11):2247-2256.
10. Hunter SK. Sex differences in human fatigability: mechanism and insight to physiological responses. *Acta Physiol.* 2014;210(4):768-789.
11. Rinard J, Clarkson PM, Smith LL, et al. Responses of male and females to high-force eccentric exercise. *J Sports Sci.* 2000;18(4):22-236.
12. Sayers SP, Clarkson PM. Force recovery after eccentric exercise in males and females. *Eur J Appl Physiol.* 2001;84:122-126
13. Lee A, Baxter J, Eischer C, et al. Sex differences in neuromuscular function after repeated eccentric contractions of the knee extensor muscle. *Eur J Appl Physiol.* 2017;117(6):1119-1130.
14. Hubal M, Rubinstein SR, Clarkson PM. Muscle function in men and women during maximal eccentric exercise. *J Strength Cond Res*. 2008;22(4):1332-1338.
15. Hicks KM, Onambele GL, Winwood K, et al. Muscle damage following maximal exccentric knee extensions in males and females. *PLoS One.* 2016;11(3):e0150848.

16. Power GA, Dalton BH, Rice, et al. Peak power is reduced following lengthening contractions despite a maintenance of shortening velocity. *Appl Physiol Nutr Metab.* 2013;38(12):1196-1205.
17. Billaut F, Smith K. Sex alters impact of repeated bouts of sprint exercise on neuromuscular activity in training athletes. *Appl Physiol Nutr Metab.* 2009;34(4):689-699.
18. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res.* 2001;15(1):109-115.
19. Hopkins WG. Spreadsheets for analysis of controlled trials, crossovers and time series (post-only crossover). *Sportscience* 2017;21:1-4 (sportsci.org/2017/wghxls.htm).
20. Hopkins WG. Spreadsheets for analysis of controlled trials, crossovers and time series (pre-post parallel-groups). *Sportscience* 2017;21:1-4 (sportsci.org/2017/wghxls.htm).
21. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform.* 2006;1(1):50-57.
22. Rosnow RL, Rosenthal R, Rubin DB. Contrasts and correlations in effect-size estimation. *Pschol Sci* 2000; 11(6):446-453.
23. Kellmann M, Altenburg D, Lormes W, et al. Assessing stress and recovery during preparation of the world championships in rowing. *Sport Psychol.* 2001;15:151-167.
24. Hogarth, LW, Burkett, BJ, McKean MR. Influence of Yo-Yo IR2 scores on internaal and external workloads and fatigue responses of tag football players during tournament competition. *PLoS ONE.* 2015;10(10): e0140547.
25. Waldron M, Highton J. Fatigue and pacing in high-intensity intermittent team sports. *Sports Med*. 2014;44(12):1645-1658.
26. Le Meur Y, Hausswirth C, Natta F, et al. A multidisciplinary approach to overreaching detection in endurance athlete. *J Appl Physiol.* 2013;114(3):411-420.
27. Oxendale C, Twist C, Daniels M, et al. The relationship between match-play charactersics of elite rugby league and indirect markers of muscle damage. *Int J Sports Physiol Perform.* 2016;11(4):515-521.
28. Di Fronso, S, Nakamura FY, Bortoli L, et al. Stress and recovery balance in amateur basketball players: differences by gender and preparation phase. *Int J Sports Phsiol Perform.* 2013; 8(6):618-622.
29. Johnston RD, Gibson NV, Twist C, et al. Physiological responses to an intensified period of rugby league competition. *J Strength Cond Res.* 2013;27:643-654.

30. Twist C, Eston, R. The effects of exercise-induced muscle damage on maximal intensity intermittent exercise performance. *Eur J Apply Physiol.* 2005;94;652-658.
31. Kendall B, Eston R. Exercise-induced muscle damage and the potential protective role of estrogen. *Sports Med.* 2002;32(2):103-123.
32. Jacobs I, Kaiser T, Tesch P. Muscle strength and fatigue after selective glycogen depletion in human skeletal muscle fibres. *Eur J Appl Physiol Occup Physiol.* 1981;46(1):47-53.

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

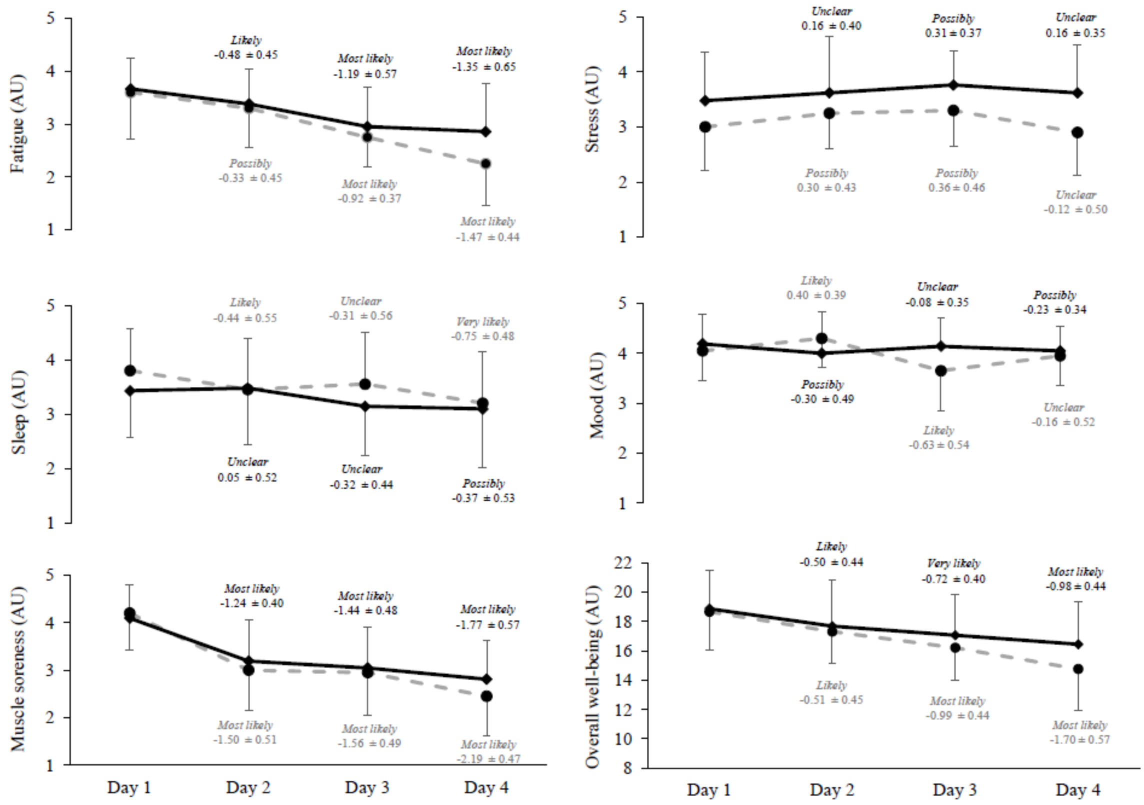
		Competition Day			
		1	2	3	4
Playing time (min)	Females	20.6 ± 9.2	21.9 ± 9.7 ^{t}	22.3 ± 7.0 ^{s**}	21.9 ± 7.3 ^{s*}
	Males	19.5 ± 8.1	18.5 ± 6.1 ^{s}	19.3 ± 6.0 ^{t}	19.7 ± 6.0 ^{t}
Total distance (m)	Females	2393 ± 782	2606 ± 1001 ^{s}	2507 ± 717 ^{s**}	2573 ± 707 ^{s**}
	Males	2350 ± 912	2436 ± 526 ^{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 ± 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.

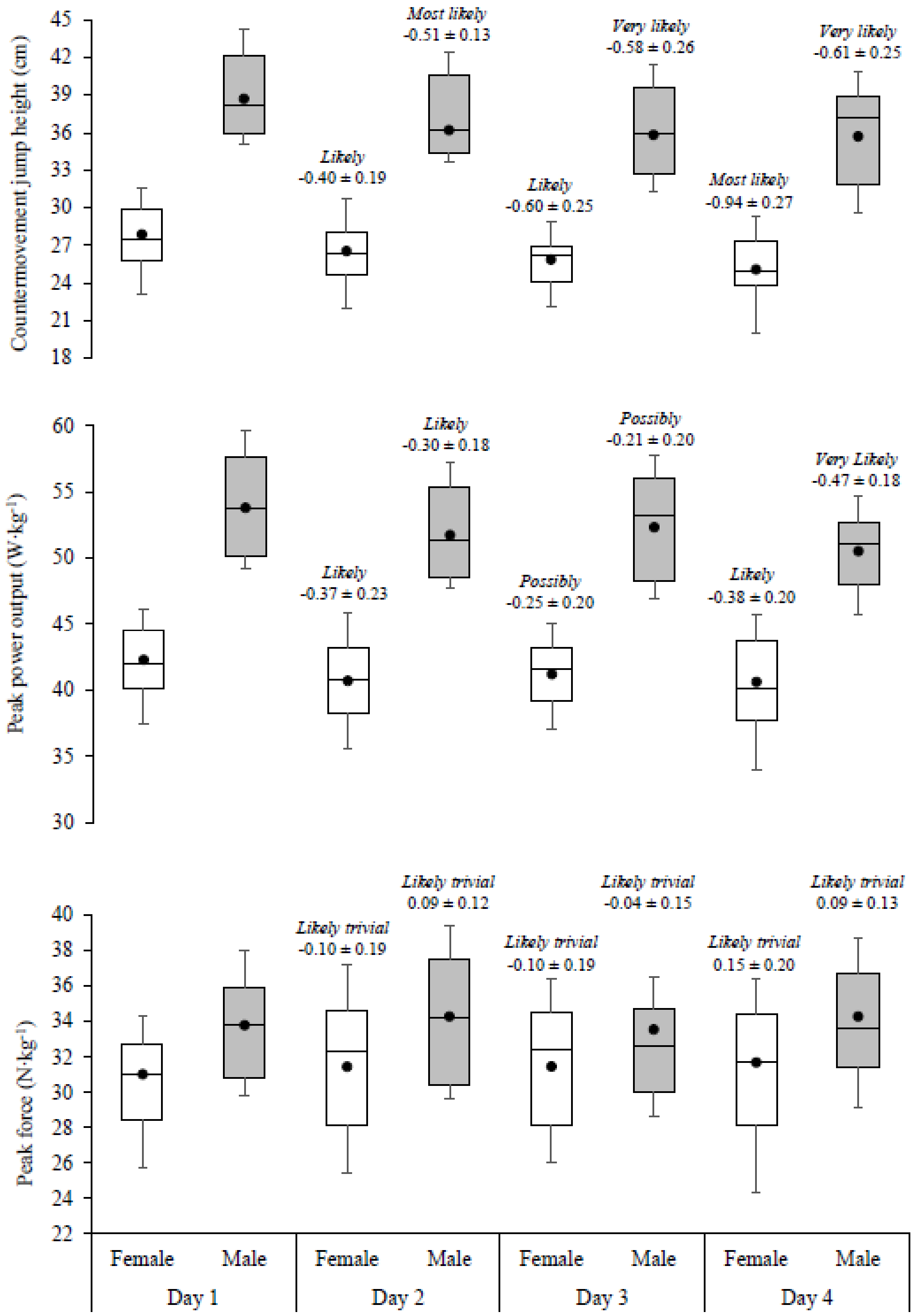
Figure 2. Mean ± SD for jump height (top), peak power (middle) and PF (bottom) for males (black solid line) and females (grey dashed line) across the tournament. Descriptors and effect sizes for male (black text) and females (grey text) are compared to day 1.

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*.



Fatigue (AU)
Likely
-0.48 ± 0.45
Most likely
-1.19 ± 0.57
Most likely
-1.35 ± 0.65
Possibly
-0.33 ± 0.45
Most likely
-0.92 ± 0.37
Most likely
-1.47 ± 0.44
Stress (AU)
Unclear
0.16 ± 0.40
Possibly
0.31 ± 0.37
Unclear
0.16 ± 0.35
Possibly
0.30 ± 0.43
Possibly
0.36 ± 0.46
Unclear
-0.12 ± 0.50
Sleep (AU)
Likely
-0.44 ± 0.55
Unclear
-0.31 ± 0.56
Very likely
-0.75 ± 0.48
Unclear
0.05 ± 0.52
Unclear
-0.32 ± 0.44
Possibly
-0.37 ± 0.53
Mood (AU)
Likely
0.40 ± 0.39
Unclear
-0.08 ± 0.35
Possibly
-0.23 ± 0.34
Possibly
-0.30 ± 0.49
Likely
-0.63 ± 0.54
Unclear
-0.16 ± 0.52
Muscle soreness (AU)
Most likely
-1.24 ± 0.40
Most likely
-1.44 ± 0.48
Most likely
-1.77 ± 0.57
Most likely
-1.50 ± 0.51
Most likely
-1.56 ± 0.49
Most likely
-2.19 ± 0.47
Overall well-being (AU)
Likely
-0.50 ± 0.44
Very likely
-0.72 ± 0.40
Most likely
-0.98 ± 0.44
Likely
-0.51 ± 0.45
Most likely
-0.99 ± 0.44
Most likely
-1.70 ± 0.57
Day 1
Day 2
Day 3
Day 4

Figure 1



Countermovement jump height (cm)
45
42
39
36
33
30
27
24
21
18
Most likely
-0.51 ± 0.13
Very likely
-0.58 ± 0.26
Very likely
-0.61 ± 0.25
Likely
-0.40 ± 0.19
Likely
-0.60 ± 0.25
Most likely
-0.94 ± 0.27
Peak power output (W·kg⁻¹)
60
55
50
45
40
35
30
Likely
-0.30 ± 0.18
Possibly
-0.21 ± 0.20
Very Likely
-0.47 ± 0.18
Likely
-0.37 ± 0.23
Possibly
-0.25 ± 0.20
Likely
-0.38 ± 0.20
Peak force (N·kg⁻¹)
40
38
36
34
32
30
28
26
24
22
Likely trivial
0.09 ± 0.12
Likely trivial
-0.04 ± 0.15
Likely trivial
0.09 ± 0.13
Likely trivial
-0.10 ± 0.19
Likely trivial
-0.10 ± 0.19
Likely trivial
0.15 ± 0.20
Female
Male
Female
Male
Female
Male
Female
Male
Day 1
Day 2
Day 3
Day 4

Figure 2

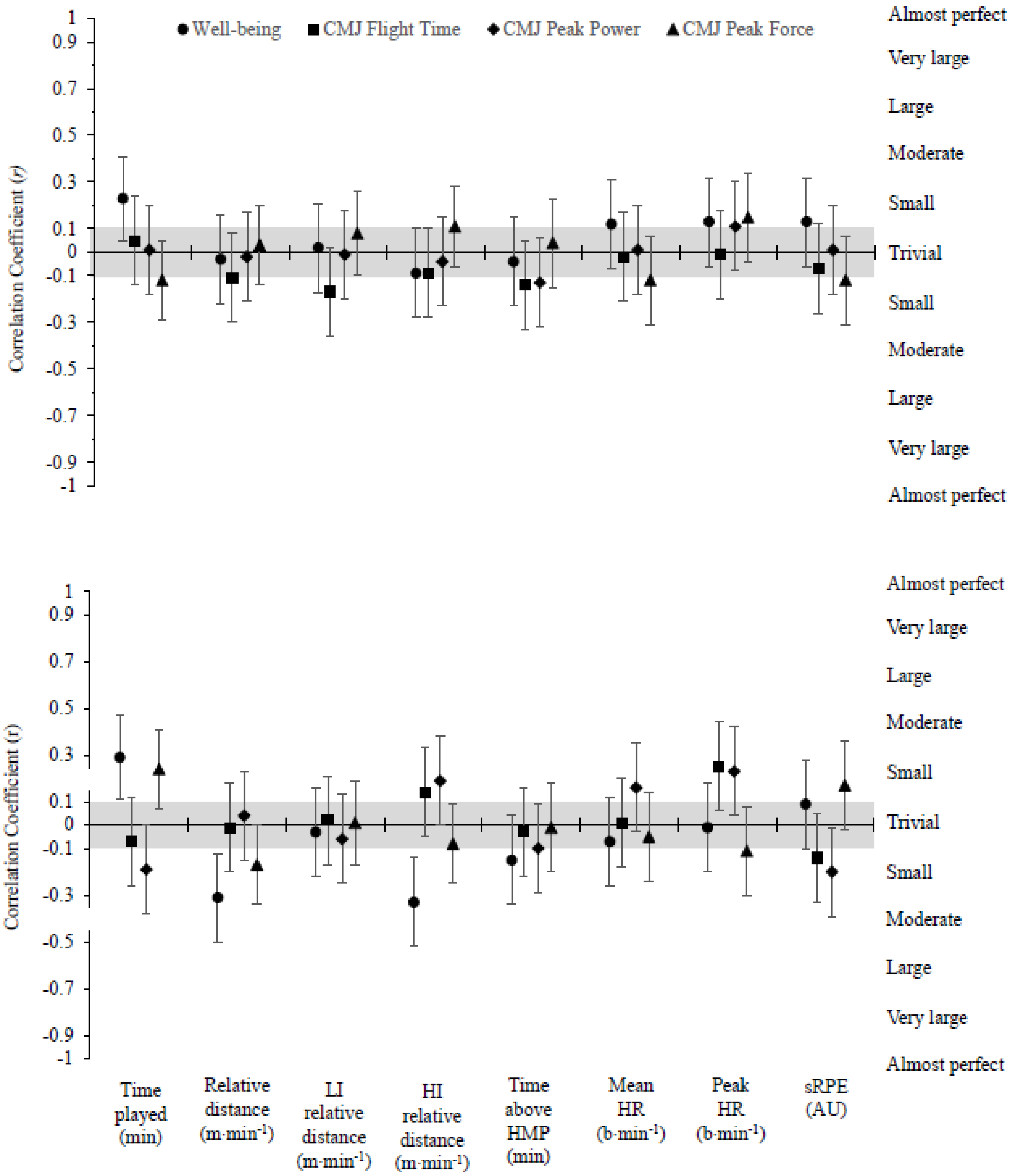

Well-being
CMJ Flight Time
CMJ Peak Power
CMJ Peak Force
Correlation Coefficient (r)
1
0.9
0.7
0.5
0.3
0.1
0
-0.1
-0.3
-0.5
-0.7
-0.9
-1
Almost perfect
Very large
Large
Moderate
Small
Trivial
Small
Moderate
Large
Very large
Almost perfect
Time played (min)
Relative distance (m·min-1)
LI relative distance (m·min-1)
HI relative distance (m·min-1)
Time above HMP (min)
Mean HR (b·min-1)
Peak HR (b·min-1)
sRPE (AU)

Figure 3