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Effect of World Lacrosse Sixes Match play on Neuromuscular Performance in International Men's Lacrosse Players

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ABSTRACT

Sixes lacrosse is a new sport to be included in the 2028 Olympics, however there is limited understanding on the demands of Sixes lacrosse competition. **Purpose:** To observe the effect of Sixes lacrosse on acute fatigue. **Methods:** Eleven international male Sixes lacrosse players (24.82 ± 2.58 years, 180.17 ± 8.84 cm, 90.14 ± 7.63 kg) participated within the present study, playing in five competitive matches over three-days. Three countermovement jump (CMJ) trials were performed pre- and post-match. **Results:** Very large (d = 1.35 [0.51-2.17]) decreases in system weight (SW), a moderate increase in jump height (JH) (d = 0.67 [-0.02-1.31]) and a moderate decrease in average relative braking force (ARBf) (d = 0.68 [-0.03-1.27]) were observed from pre-post one match. A moderate (d = 0.76 [0.07-1.42]) decrease in SW, with a small increase in average relative propulsive force (ARPf) (d = 0.30 [-0.31-0.90]) were observed from pre-post three matches. Very large increases in JH (d = 1.69 [0.73-2.61]) and time to take off (d = 1.43 [-0.40-2.45]) with a large increase in countermovement displacement (d = 1.05 [0.29-1.78]) and a large decrease in ARBf (d = 0.84 [0.13-1.52]), with no meaningful changes were observed for SW (d = 0.03 [-0.56-0.62]), or ARPf (d = 0.04 [-0.56-0.63]) observed from pre-post international tournament. **Conclusion:** The results of this study have implications on recovery within Sixes lacrosse players during international tournaments. Moreover, the high levels of observed fatigue would likely require a period of restitution following international tournament.

Keywords: Tournament; Fixtures; Fatigue; Countermovement jump (CMJ); Condensed.

INTRODUCTION

Recently, a small-sided format of field lacrosse, called Sixes Lacrosse has been designed, involving 6 vs. 6 players consisting of one goalkeeper and five "outfield" players with no formal positions or position-specific rules (e.g., offside rules in relation to each of the positions). Matches are played over a period of 32 minutes (four x 8 min quarters) on a playing area 70 m x 36 m. Sixes lacrosse uses rolling substitutes with unlimited interchanges being permitted, potentially changing the intensity or the design of pacing strategies. With the addition of a 30 second shot clock whereby a team must shoot or turn over possession within the designated timeframe, increases the intensity of the smaller-scale game akin to 3 x 3 basketball. Sixes lacrosse has received confirmation of its inclusion for the 34th edition of the summer Olympics [1]. However, given it is less than one Olympic cycle (4 years) since the inception of Sixes lacrosse. There remains a limited amount of information available on the demands international Sixes lacrosse competition places upon athletes with regards to neuromuscular function (NMF). Currently, there are two studies in which the researchers report the match demands of Sixes lacrosse; one studying in-house training matches [2] and one observing international competitive fixtures [3]. Identifying the demands of international Sixes lacrosse is essential information for practitioners working for optimal physical preparation. Moreover, understanding the fatiguing effect of match performance would also be important for physical preparation coaches and medical practitioners to prepare athletes for the demands for and within competition. Currently international competition structure is to have short weekend tournaments with multiple fixtures in condensed period of 3-4 days, which can include up to three fixtures within a single day, highlighting the importance of understanding the demands and fatiguing effect of international Sixes lacrosse.

Acute negative alterations in physical preparedness are likely to effect on-field physical output and increase the potential for non-contact injuries [4-6]. As per the fitness-fatigue paradigm, the optimisation of physical preparedness can be achieved through enhancements in physical fitness and the mitigation and recovery from physical fatigue [4]. However, athlete's internal response to a physical stimulus (i.e., external workload) is individual [7]. As high-intensity external workload differs between competing athletes, the levels of neuromuscular fatigue and preparedness will differ between athletes following training and competitive matches [8]. Subsequently, accurately managing physical preparedness is desirable in elite team sports to reduce the risk of non-contact injury and optimise physical output. Specific thermoregulatory strategies have been proposed to aid recovery, however in the absence of fatigue monitoring processes, a generic approach of utilising cooling and heating is prescribed to accelerate recovery 9. Objective measure of changes in NMF can help to identifying the magnitude of fatigue an athlete has incurred, which would help practitioners prescribe systematic strategies and time periods to optimise recovery [9].

The countermovement jump (CMJ) is the most popular test used to assess longitudinal developments in NMF in team sports [10]. Thorlund et al. [11] identified a significant (p<0.01) reduction in jump height (JH) (5.2%) from pre- to post-simulated handball match when using the CMJ. Similarly, Gathercole et al. [6] identified a reduction in JH, albeit with a small effect size (0.34) from a high-intensity intermittent-exercise running test. Within female collegiate field lacrosse Frick et al.[12] used the CMJ to observe NMF across pre-season and in-season to determine in conjunction with a wellness questionnaire as a subjective measure of fatigue. Although there was small (effect size = 0.28) variation in CMJ height across the observation period, there were only trivial correlations with wellness and specific matches or demands were not reported [12]. Moreover, the authors used a just jump mat which has been shown to overestimate JH [13], while also not accounting for alternate jump metrics which can derived from a force plate. This is potentially problematic as the outcome of a CMJ test might not necessarily be hindered following intense physical activity as athletes could alter their jump strategy (i.e., increase time to take-off (TTTO), and/or countermovement depth (CD) to maintain net propulsive impulse), and thus, JH might not be the best indicator of acute changes in NMF [5]. Spencer et al. [14] found no significant difference in JH from pre-post competitive soccer match, with a significant (p<0.05) reduction in body mass, jump momentum, and CD. A maintenance of JH when body mass has decreased indicates a negative change in kinetic output, specifically, less propulsive impulse has been produced, as it is relative net propulsive impulse (i.e., net propulsive impulse divided by body mass) that determines velocity at take-off and therefore JH [15-17]. Therefore, it may be prudent for practitioners to consider a combination of categories, such as ratio (e.g., modified reactive strength index [mRSI]), strategy (e.g., TTTO, CD), and kinetic (e.g., mean and peak propulsive force and power) measures for acute monitoring, rather than assessing the outcome (e.g., JH) alone to provide a better representation of changes in NMF over time [5,6]. Therefore, the purpose(s) of the present study were to observe if International Sixes lacrosse match play and competition format impacts NMF, assessed via a CMJ based on a combination of metrics, specifically observing if any differences were observed pre-post-match one match, pre-post three matches in a single day (which is the worst-case scenario for Sixes lacrosse players) and pre-tournament compared to post international tournament. It was hypothesised that a single international Sixes lacrosse match would have minimal effect on neuromuscular performance. However, multiple matches, either three matches in a single day and the international tournament, would result in meaningful decreases in neuromuscular performance.

METHODS

Study Design

An observational design was used to observe neuromuscular fatigue during World Lacrosse Sixes competition in international male Sixes lacrosse players during international competition. Within an international competition, neuromuscular fatigue was monitored across several timepoints across the three-day schedule (Table 1). An a *priori* sample size estimation was performed with a alpha error probability of 0.05, statistical power of 0.80 and an effect size of 0.59 for immediately post-match and 0.80 for 24 hours post-match based on the meta-analysis performed by Hagstrom and Shorter [18], providing a required sample size of 20 and 12, respectively.

Participants

International male outfield Sixes lacrosse players (n = 11, 24.82 ± 2.58 years, 180.17 ± 8.84 cm, 90.14 ± 7.63 kg) participated within the present study, playing in five competitive matches over a three-day (n = 55 observations) period, which is the typical competition format of World Lacrosse Sixes international events. It is worth noting that the included sample is lower than the required sample, which is due to only having access to a single international Sixes lacrosse squad, which is capped to 12 players.

All players were part of the international Sixes lacrosse squad and selected for the international tournament. Players were included within the present study if they were outfield players selected within the 12-player tournament squad. There was no minimum match play duration due to continuous nature of all Sixes lacrosse, players would have only been removed if they were injured during the match and could not continue within the match. Match performance from a tactical perspective was kept relatively consistent for the entire tournament with only slight adjustments to overall playing style, meaning there would be minimal impact on activity profiles. This study was approved by the Ethics Review Board of University of Salford (ID number 9603) and conducted in accordance with the Declaration of Helsinki (2013). All players provided written informed consent and were ensured the anonymity of data and identities.

Measurements

Instrumentation

To collect locomotion data, GPS microtechnology sampling at 10 Hz (Vector S7; Catapult Sports, Melbourne, Australia) were utilised. All players wore the GPS units within a fitted sports vest under all protective equipment (Catapult Sports, Melbourne, Australia) with a pocket positioned between the scapulae to hold a microsensor, which included a 10 Hz GPS chip and 100 Hz triaxial accelerometer. The validity of GPS technology has been deemed acceptable for measuring movements associated with team sports competition [19-21]. All GPS microsensors were activated 10 minutes before match preparation to ensure a clear satellite reception, all players were familiar with the equipment and protocols being conducted for data acquisition. Openfield software (version 3.7.0; Catapult Sports) was used to manually identify the start and end of each 8-minute quarter from GPS data following acquisition, with the start and end of each quarter being time matched. Thereafter, raw data from each match were exported into a Google sheets spreadsheet (California, USA) to process the variables for analysis. Speed zone thresholds and minimum time used to identify efforts were as per original proprietary software.

Table 1. Schedule of matches and pre-post countermovement jump (CMJ) collection

Day 1	Day 2	Day 3
Pre-CMJ; Time = 13:15-13:22	Pre-CMJ; Time = 09:12-09:21	
	Match #2; Time =10:00	Pre-CMJ; Time = 13:15-13:22
Match #1; Time =14:00	Post-CMJ; Time = 10:51-11:03	
	Pre-CMJ; Time = 14:17-14:28	
	Match #3; Time =15:00	Match #5; Time = 14:00
	Post-CMJ; Time = 15:50-15:58	
Post-CMJ; Time = 14:50-15:05	Pre-CMJ; Time = 17:14-17:25	
	Match #4; Time =18:00	Post-CMJ; Time = 14:54-15:08
	Post-CMJ; Time = 18:53-19:01	

Pre-CMJ = Pre-match countermovement jump, Post-CMJ = post-match countermovement jump

Geolocation information

Locomotion data was collected in Monte Gordo (Portugal). Data was exported and analysed in Manchester (United Kingdom). The average and minimum number of satellites identified across the observation period was (18.2 ± 1.0, 16) and the average horizontal dilution of precision across the observation period was (0.88 ± 0.15) [22].

Locomotive demands

Various activity variables were measured to comprehensively quantify the locomotive demands of international Sixes lacrosse matches under World Lacrosse Sixes rules, from inception to the World Games 2022. Data were collected and reported for the entire match irrespective of whether players were actively competing or substituted because of the dynamic nature of substitutions. Data were not collected during the 2-minute inter-quarter breaks or 5-minute half-time break during each match. Furthermore, no timeouts were used, or stoppages occurred during the monitored matches. The GPS component of the microsensors was used to measure the absolute (m) and average speed (AS) ($m \cdot min^{-1}$) and distances covered performing various speed-mediated activities, including walking and jogging (<4 $m \cdot s^{-1}$), running (4–5.49 $m \cdot s^{-1}$), high-speed running (HSR) (5.5-7.0 $m \cdot s^{-1}$) and very high speed running (VHSR) (>7.0 $m \cdot s^{-1}$), with maximum velocity ($m \cdot s^{-1}$) also recorded. AS values were determined as the distance covered relative to the duration of each quarter (8 minutes) and entire matches (32 minutes).

Triaxial accelerometers were used to detect the frequency (count) of accelerations (>2 $m \cdot s^2$), decelerations (>-2 $m \cdot s^2$). The various intensity and speed thresholds used required a 1-second minimum effort duration to record acceleration and deceleration counts, were in line with the manufacturers' recommended default settings and previous research in field lacrosse [23].

Neuromuscular performance monitoring

The pre-match CMJ testing was performed approximately 15 minutes before the match warm up. A standardised warm up, consistent of squats, lunges, leg swings and 3 familiarisation trials consisting of a submaximal effort CMJ was provided for each participant. The post-match CMJ testing was performed immediately (within 5-15 minutes post-match) following the completion of the match for every athlete.

Participants performed three maximal effort CMJ trials with arms akimbo and were instructed to jump "as fast and high as possible" on each testing occasion. Participants were reminded of the verbal cues in the rest period before the commencement of the next trial. A between-trial rest period of ~30 seconds was prescribed for every recorded trial. A trial was excluded if hands left the hips or if deviations in body position were observed during the flight as this could impact propulsive strategy.

During every testing session, the vertical component of GRF data (filtered at 50 Hz) was collected using a wireless and portable dual force plate system, by Hawkin Dynamics Inc. (Maine, USA), at 1000 Hz, over 6 seconds. Hawkin Dynamics Inc. proprietary software was downloaded onto an electronic tablet device ("Android" mobile operating system) which connected to the force plates via "Bluetooth". This proprietary software was used to produce force-time curves, and, in CMJ tests, forward dynamics was applied to calculate a multitude of performance variables relating to acceleration, velocity, and displacement [24]. All trials were conducted on solid, even, non-slip flooring. Zeroing of the force plates was performed between participants.

Data analysis was automatically performed after each trial via the Hawkin Dynamics Inc. proprietary software. The onset of movement was determined based on exceeding a threshold of 5 SDs of the force during the period of quiet standing (i.e., the weighing phase), with subsequent metrics calculated using a forward dynamics approach. A full description of the start of numerical integration and phase descriptions for the CMJ test (i.e., weighing, unweighting, braking, propulsion, and flight phases) is presented by [24].

Metrics were selected based on representation of person, jump outcome, jump drivers (i.e. kinetics) and jump strategy, following the PODS acronym (Person, Outcome, Driver and Strategy), as described by Ripley et al. [25] (Table 2). All calculations were performed within the Hawkin Dynamics Inc. proprietary software.

STATISTICAL ANALYSES

Three CMJ trials were completed at each time-point, with the average used for all within-group comparisons. The Shapiro–Wilk test was applied to

Table 2. Metric calculation presenting Person, Outcome, Driver and Strategy aspects of jump performance

CMJ aspect	CMJ metric	Abbreviation	Calculation
Person	System weight	SW	Average system weight from the 1 second quiet standing period
Outcome	Jump height	JH	Vertical velocity of the system centre of mass at the instant of take-off (identified as when force <25 N)
	Jump momentum	JM	Body mass × centre of mass velocity at take-off
	Modified reactive strength index	mRSI	JH divided by the TTTO (i.e. total time taken from the initiation of movement to the instant of take-off)
Driver	Average relative braking force	ARBf	Average vertical ground reaction force applied to the system centre of mass during the braking phase divided by body mass
	Average relative propulsive force	ARPf	Average vertical ground reaction force applied to the system centre of mass during the propulsive phase divided by body mass
Strategy	Countermovement depth	CD	Peak negative vertical displacement of the system centre of mass during the countermovement phase, calculated by numerically integrating the velocity-time record (derived from the acceleration-time record [calculated by dividing the net force-time record by body mass]) using the trapezoid rule
	Time to take off	TTTO	Time from initiation of movement (identified as a change in force >5 standard deviations during the period of quiet standing) to the instant of take-off (identified as when force reaches <25 N)

assess the data distribution. Descriptive statistics were calculated and are presented as the mean ± the standard deviation (SD) for all variables. The absolute between-trial reliability, based off the pre-match 1 trials, for each variable was calculated using the coefficient of variation percentage (CV%), with values were interpreted based of the upper bound 95% confidence interval of ≤5.00%, 5.01-10.00%, 10.01-15.00% and ≥15.00% considered to represent excellent, good, moderate and poor absolute reliability, respectively. The relative between-trial reliability was assessed via a two-way random-effects intraclass correlation coefficient (ICC) based on the three trials performed pre-match 1. ICC values were interpreted based of the lower bound 95% confidence interval <0.5, between 0.5 and 0.75, between 0.75 and 0.90, and >0.90 were classified as poor, moderate, good, and excellent relative reliability, respectively [26]. Minimal detectable change (MDC) was calculated by multiplying the square root of SEM^2 by 1.96. This was also expressed as a percentage by dividing MDC by the pooled mean and multiplying by 100. The MDC was used to determine meaningful difference.

A series of dependent t-tests were performed to examine the best to worst case scenario for a single day, plus the effect of the entire international tournament on neuromuscular fatigue. Dependent t-tests were Bonferroni corrected due to the increased risk of type 1 error. Therefore, the effect of Sixes Lacrosse match play (pre-post-match match one [pre-match 1 from day 1 vs. post-match match 1 day 1], pre-post three matches in a single day [pre-match 2 from day 2 vs. post-match 4 from day 2] and pre-post international tournament [pre match 1 from day 1 vs. post-match 5 from day 3]) of neuromuscular performance. Effect sizes were calculated using the Cohen's *d* method and associated 95% CI, providing a measure of the magnitude of the differences noted in each variable between time points, and were interpreted as trivial (≤0.19), small (0.20 to 0.49), moderate (0.50 to 0.79), large (0.80-1.19), or very large (≥1.20) [27]. All data were analyzed within JASP (Version 0.18.2 [Computer software]) with data being bootstrapped to 10,000 samples to minimise the impact of the lower than required sample size. Bootstrapping the data increases the accuracy of the 95% CIs for the effect sizes, with statistical significance accepted at $p \leq 0.05$ [28].

RESULTS

Reliability

Reliability data are presented in table 3, with

Table 3. Descriptive and reliability statistics from pre to post one match, pre to post three matches and pre to post international tournament

Metric	CV% (95% CI)	ICC (95% CI)	MDC (%)	PRE-1M Mean ± SD	POST-1M Mean ± SD	PRE-3M Mean ± SD	POST-3M Mean ± SD	PRE-IT Mean ± SD	POST-IT Mean ± SD
SW (N)	0.05 (0.04-0.06)	0.999 (0.998-1.000)	4.64 (0.55)	834.81±74.38	825.29±72.46$	857.64±82.78	845.15±73.91#	834.81±74.38	837.86±78.41
JH (m)	3.35 (2.58-4.12)	0.925 (0.817-0.976)	0.03 (6.94)	0.37±0.05	0.39±0.05	0.39±0.06	0.39±0.06	0.37±0.05	0.41±20.48&
JM (kg·m/s)	1.68 (1.29-2.07)	0.961 (0.901-0.988)	7.89 (3.42)	228.80±20.47	231.25±22.57	239.35±24.70	237.09±24.61	236.98±20.47	245.64±25.97&
CD (m)	8.52 (6.55-10.48)	0.923 (0.812-0.975)	0.05 (16.98)	0.32±0.10	0.30±0.09	0.33±0.09	0.33±0.08	0.32±0.10	0.37±0.04&
ARBf (N/kg)	5.43 (4.18-6.68)	0.667 (0.354-0.877)	24.35 (12.49)	200.47±16.66	188.93±17.03	190.77±13.94	192.30±14.53	200.47±16.66	171.44±11.54&
ARPf (N/kg)	3.02 (2.32-3.72)	0.870 (0.699-0.957)	14.46 (6.78)	212.33±20.73	217.32±21.93	207.92±18.58	212.99±17.10	212.33±20.73	213.16±10.18
TTTO (s)	11.25 (8.65-13.85)	0.686 (0.330-0.990)	0.11 (13.54)	0.66±0.05	0.76±0.15	0.75±0.10	0.75±0.11	0.66±0.05	0.83±0.09&
mRSI (AU)	10.21 (7.85-12.57)	0.675 (0.366-0.881)	0.10 (21.23)	0.48±0.09	0.54±0.11	0.50±0.07	0.53±0.09	0.48±0.09	0.58±0.06&

CV% = coefficient of variation percentage, ICC = intraclass correlation coefficient, 95% CI = 95% confidence intervals, MDC = minimal detectable change, 1M = 1 match, 3M = 3 matches, IT = international tournament, SD = standard deviation, SW = system weight, JH = jump height, JM = jump momentum, CD = countermovement depth, ARBf = average relative braking force, ARPf = average relative propulsive force, TTTO = time to take off, mRSI = modified reactive strength index, $ = meaningful decreased from pre match 1, # = meaningful decrease from pre 3 matches, & = meaningful increase from pre international tournament

Table 4. Descriptive statistics for external GPS demand for each match across the tournament.

Match	TD (m)	MV ($m \cdot s^{-1}$)	AS ($m \cdot min^{-1}$)	Walking and Jogging distance (m)	Running distance (m)	HSR distance (m)	VHSR distance (m)	Number of accelerations (#)	Number of decelerations (#)
1	3213.11 ± 567.98	8.20 ± 0.43	97.60 ± 1.52	1872.44 ± 350.78	801.33 ± 142.75	429.78 ± 91.42	189.56 ± 13.03	27.11 ± 2.30	17.90 ± 7.91
2	2927.35 ± 492.94	7.80 ± 0.28	106.10 ± 7.59	1654.33 ± 300.52	724.78 ± 106.47	452.69 ± 105.08	185.56 ± 20.86	25.44 ± 5.30	14.10 ± 11.33
3	2976.97 ± 574.47	8.05 ± 0.52	94.40 ± 14.00	1631.42 ± 353.46	657.81 ± 149.15	559.44 ± 119.29	187.33 ± 12.57	27.78 ± 3.79	23.10 ± 9.80
4	2911.40 ± 548.94	8.00 ± 0.21	101.40 ± 3.37	1267.00 ± 208.52	774.50 ± 124.75	674.50 ± 115.26	195.00 ± 10.41	23.10 ± 6.40	24.50 ± 6.70
5	3072.93 ± 425.51	8.12 ± 0.19	100.70 ± 4.36	1372.61 ± 391.17	816.04 ± 366.44	697.10 ± 99.77	187.17 ± 18.14	26.40 ± 5.89	22.00 ± 8.25

TD = total distance, MV max velocity, AS = average speed, HSR = high speed running, VHSR = very high-speed running excellent to poor relative reliability and excellent to moderate absolute reliability observed for the metrics derived from the CMJ, with the latter (absolute reliability [CV%]) being more important for acute monitoring purposes.

Descriptive data (mean ± SD) for pre and post one match, pre and post three matches and pre and post the international tournament are also presented in table 3. Descriptive data (mean ± SD) for GPS match demands tournament are presented in table 4, trivial-moderate differences in total distance (*d* [95% CI] = 0.03-0.54 [-1.39 – 1.07]) and sprint distance (*d* [95% CI] = 0.01-0.66 [-1.38 – 1.74]). Trivial to large differences for maximum speed (*d* [95% CI] = 0.13-1.10 [-2.00 – 2.03]), running distance (*d* [95% CI] = 0.05-0.98 [-1.87 – 2.11]), acceleration (*d* [95% CI] = 0.17-0.89 [-1.77 – 1.49]) and deceleration efforts (*d* [95% CI] = 0.12-1.12 [-1.23 – 2.21]). Trivial to very large differences in average speed (d [95% CI] = 0.18-1.55 [-1.93 – 3.53]) and walking distance (*d* [95% CI] = 0.07-2.10 [-3.14 – 3.58]). A small-very large differences in high-speed running distance (*d* [95% CI] = 0.23-2.79 [-0.63 – 4.47]). These differences highlight some variability in the match demands, despite the consistency of match performance from a tactical perspective.

Pre to Post one match

Very large (*d* = 1.35 [0.51-2.17]) decrease in SW, with a moderate increase in JH (*d* = 0.67 [-0.02-1.31]) and a moderate decrease in ARBf (*d* = 0.68 [-0.03-1.27]) observed from pre-post one match. No meaningful changes in mRSI (*d* = 0.46 [-0.17-1.08]), JM (*d* = 0.40 [-0.22-1.01]), CD (d = 0.40 [-0.23-1.00]), ARPf (*d* = 0.45 [-1.06-1.82]) and TTTO (*d* = 0.24 [-0.37-0.83]) were observed from pre-post one match (Figure 1-2, Table 2).

Pre to Post three matches

Moderate (*d* = 0.76 [0.07-1.42]) decrease in SW, with a small increase in, mRSI (*d* = 0.47 [-0.17-1.08]) and ARPf (*d* = 0.30 [-0.31-0.90]) were observed from pre-post three match. No meaningful changes were observed within JH (*d* = 0.10 [-0.69-0.48]), JM (*d* = 0.09 [-0.49-0.68]), CD (*d* = 0.01 [-0.59-0.59]), ARBf (*d* = 0.12 [-0.48-0.71]) and TTTO (*d* = 0.00 [-0.59-0.59]) were observed from pre-post three matches (Figure 3, Table 2).

Pre to Post international Tournament

Very large increases in JH (*d* = 1.69 [0.73-2.61]) and TTTO (*d* = 1.43 [-0.40-2.45]) with a large increase

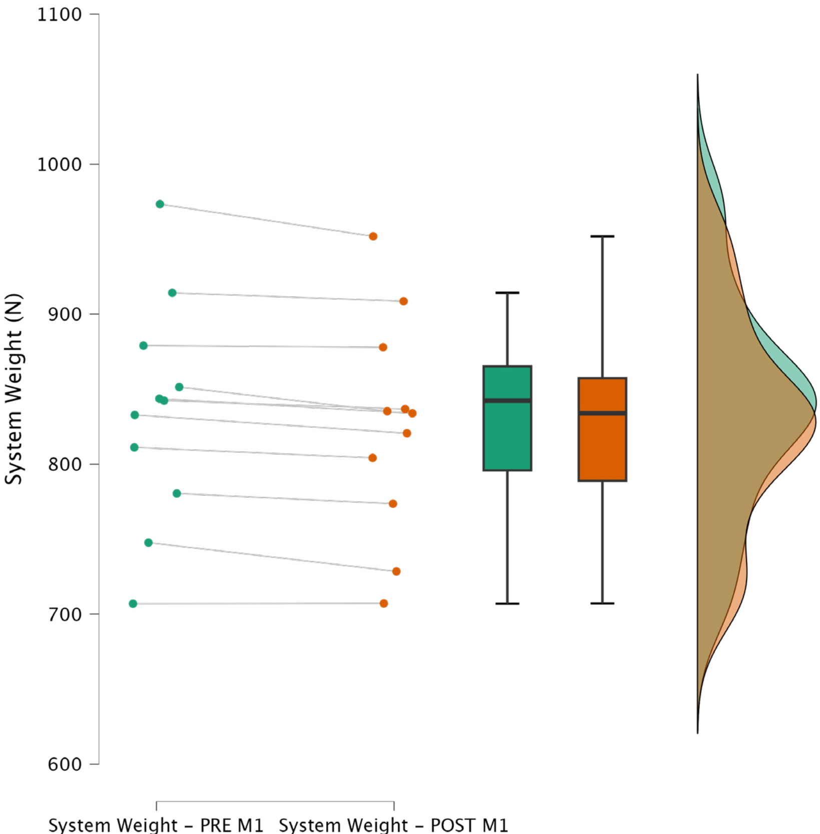

Figure 1. Individual changes, box and whisker (median) and data distribution in system weight pre and post a single Sixes lacrosse international match (M1 = match 1 on day 1, table 1).

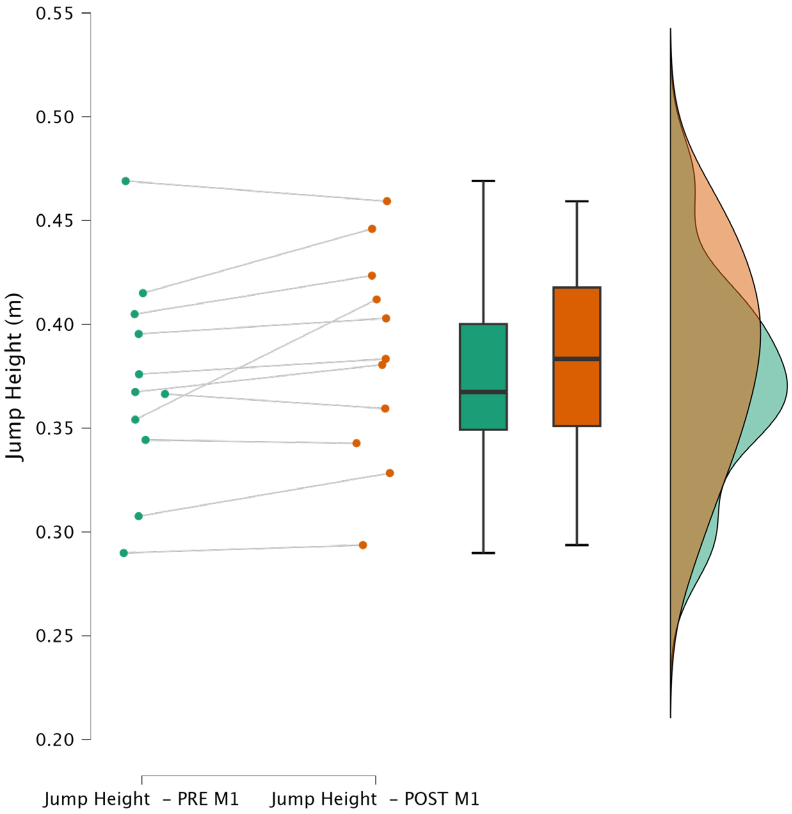

Figure 2. Individual changes, box and whisker (median) and data distribution in jump height pre and post a single Sixes lacrosse international match.

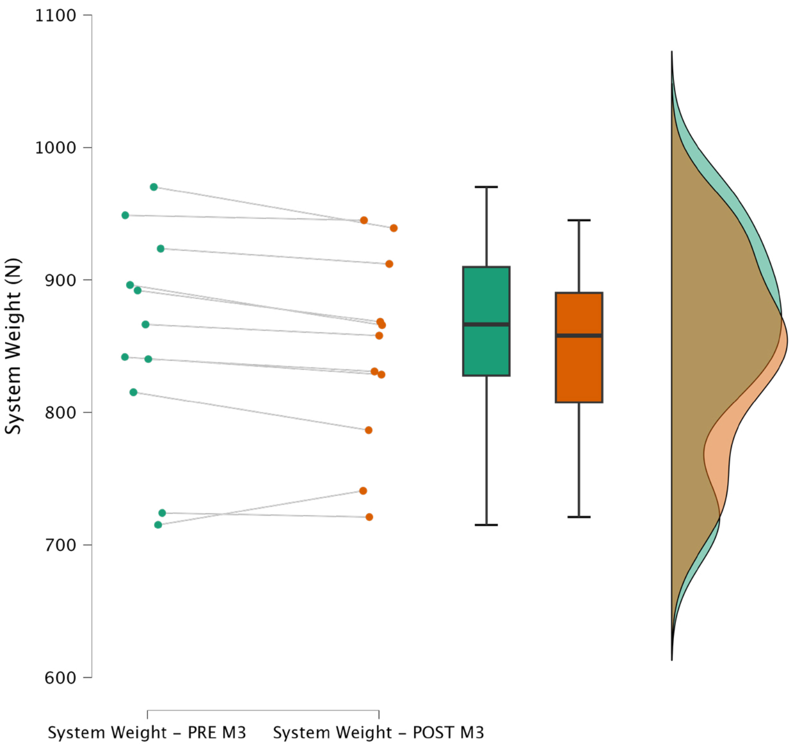

Figure 3. Individual changes, box and whisker (median) and data distribution in system weight pre and post a three Sixes lacrosse international matches in a single day (Pre M3 relates to pre match 2 [day 2] and POST M3 relates to post-match 4 [day 2], table 1).

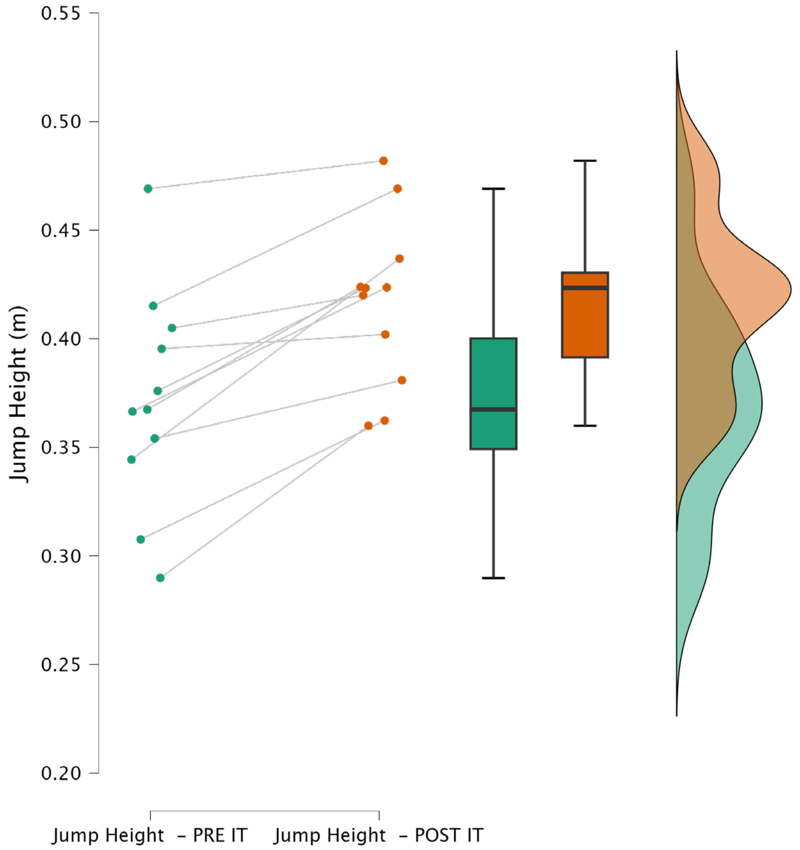

Figure 4. Individual changes, box and whisker (median) and data distribution in jump height pre and post a Sixes lacrosse international tournament.

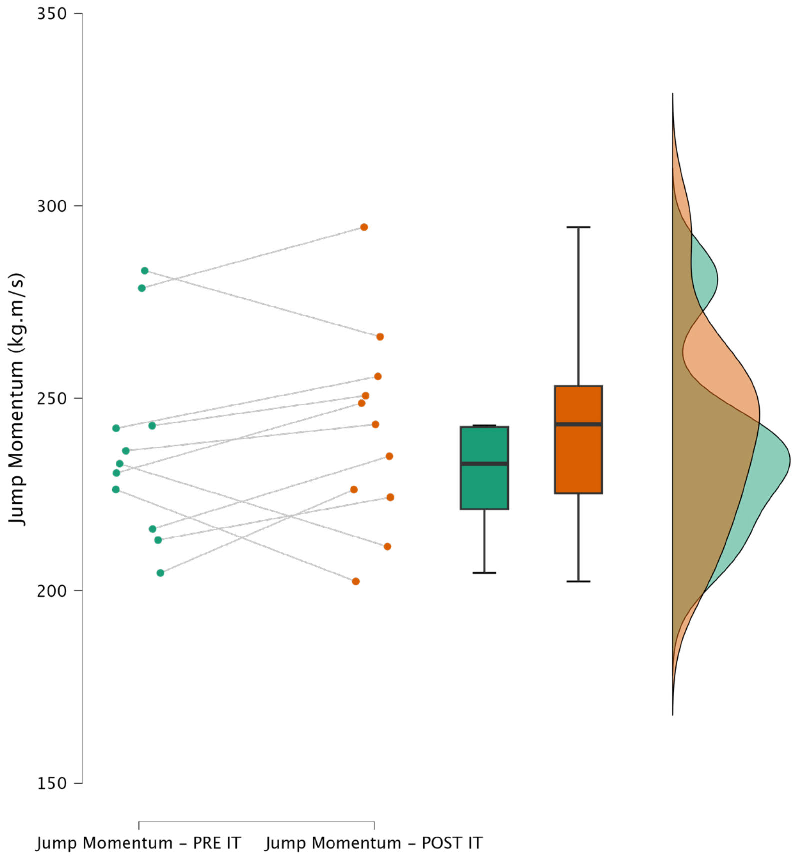

Figure 5. Individual changes, box and whisker (median) and data distribution in jump momentum pre and post a Sixes lacrosse international tournament (IT).

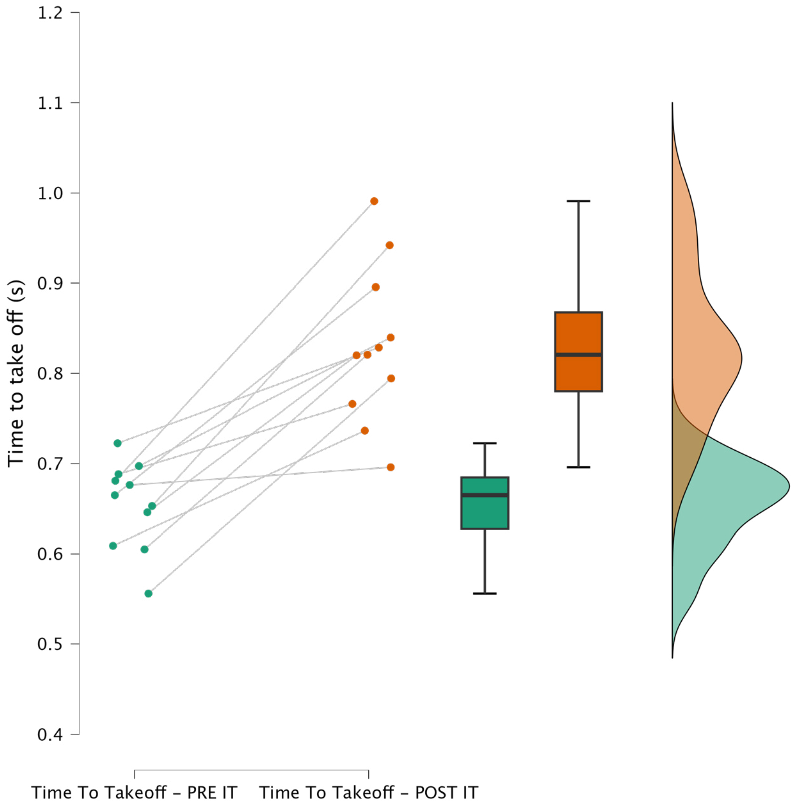

Figure 6. Individual changes, box and whisker (median) and data distribution in jump time to take off pre and post a Sixes lacrosse international tournament.

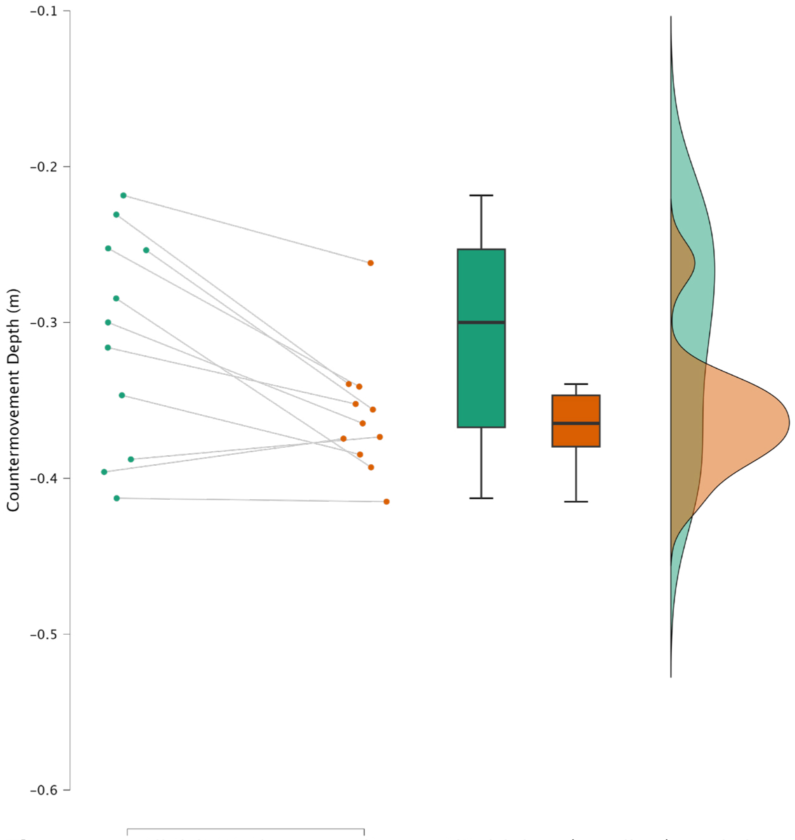

Figure 7. Individual changes, box and whisker (median) and data distribution in countermovement depth pre and post a Sixes lacrosse international tournament.

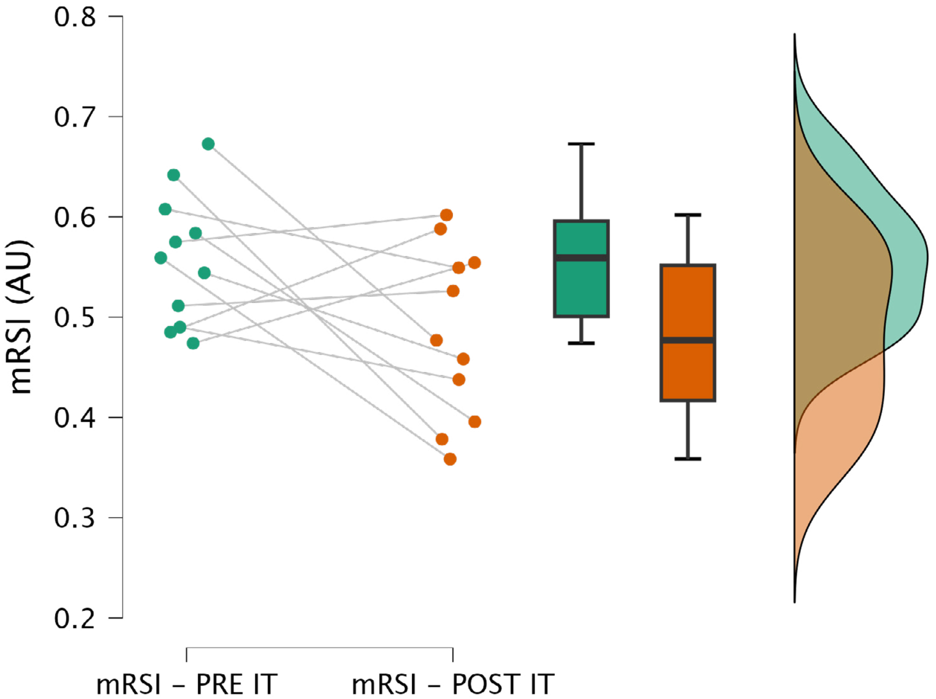

Figure 8. Individual changes, box and whisker (median) and data distribution in modified reactive strength index pre and post a Sixes lacrosse international tournament.

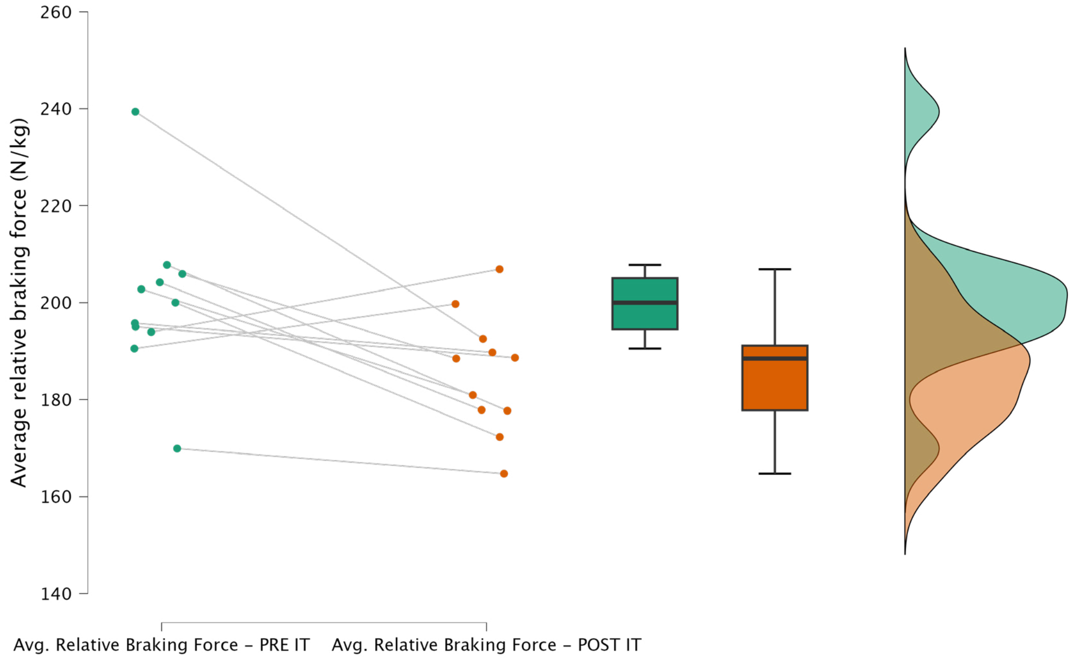

Figure 9. Individual changes, box and whisker (median) and data distribution in average relative braking force pre and post a Sixes lacrosse international tournament.

in CD (d = 1.05 [0.29-1.78]) and a large decrease in ARBf (d = 0.84 [0.13-1.52]) were observed from pre-post international tournament, respectively. A moderate decrease in mRSI (d = 0.60 [-0.06-1.23]) was observed from pre-post international tournament. A small increase in JM (d = 0.27 [-0.33-0.87]) was also observed from pre-post international tournament. No meaningful changes were observed for SW (d = 0.03 [-0.56-0.62]), or ARPf (d = 0.04 [-0.56-0.63]) pre-post international tournament (Figure 4-8, Table 2).

DISCUSSION

The purpose(s) of this study were to determine if international Sixes lacrosse match play and competition format impacts NMF, assessed via a CMJ. The hypothesis can be partially accepted, as there was evidence of fatigue from a single match. Interestingly there was minimal levels of fatigue were observed from the effect of three international Sixes lacrosse played on a single day. Following the international tournament, including five Sixes lacrosse matches, there were meaningful levels of change in NMF, which could be indicative of fatigue. The results of this study have clear implications on requirements and methods of recovery within Sixes lacrosse players during international tournaments. Moreover, following an international tournament the high levels of observed fatigue would likely require a period of restitution with implications on training following international tournament.

Monitoring acute NMF following a single competitive Sixes lacrosse match highlighted that SW had a large influence on observed changes, with a meaningful decrease from pre to post match. These findings are consistent with the findings of Spencer et al. [14], where a large decrease in body mass was observed from pre to post match within soccer players, which permitted the maintenance of JH, which is in contrast the present study. If the athletes' mass is reduced, through water lost during the match, the force required to achieve the same impulse and therefore acceleration and vertical velocity at take-off will be lower. The reduced SW (i.e., body mass) could also explain the reduced ARBF, although non-meaningful, the required force during the braking phase to stop the downward momentum would be lower. This is especially true when this is applied over a longer epoch, with a small increase observed in TTTO. This could signify that a single competitive Sixes lacrosse match does not impact NMF of athletes, however, the very large decrease in SW, indicates that rehydration protocols need to be in place following the match.

Current tournament structures for international Sixes lacrosse are focused on multiple fixtures in a short period of time, for example a three-day tournament with multiple fixtures each day. The maximum fixture congestion for the observed cohort was three matches in a single day (day 2, table 1). Consistent with a single fixture, there was a meaningful decrease in SW from pre- to post-three competitive matches, interestingly there was a meaningful increase from match one signifying that recovery strategies employed following match one was effective. Consistent with one match, there was no change in jump outcome (JH and JM), which again could be explained by decreased SW as to achieve the same jump height a reduced net propulsive impulse is required as the take-off velocity that determines JH is equal to the net propulsive impulse divided by body mass [29]. There was also no meaningful change observed within the strategy and kinetics related to jump performance. With trivial-small non-meaningful increases in ARBF and ARPF, indicating the greater force requirement to maintain maximal jump performance, which when applied over the same epoch (TTTO) over a similar displacement (CD). Despite the small increase in ARPF with no change in TTTO, it would have been expected to result in an increased CMJ outcome due to increased net propulsive impulse. However, this was not the case potentially highlighting that changes in jump performance could be related to metabolic fatigue and not neuromuscular fatigue after multiple matches within a single day. Metabolic fatigue could be induced following multiple Sixes lacrosse matches within a single day through the accumulation of hydrogen ions affecting enzymatic actions of adenosine triphosphate and phosphocreatine hydrolysis and increase in acetylcholinesterase during neurological transmissions [30,31], although this is purely speculative. Recently researchers have shown that metabolic fatigue can be discriminated by force plates, but this requires further investigation .

Across the international tournament, meaningful effects on jump outcome, strategy and kinetics were altered, while there was no change in SW. The large increases in CD and TTTO permits the greater time and distance to generate a propulsive net impulse and work, respectively. The increases in CD and TTTO were larger than the upper bound 95% CI for the CV and greater than the MDC. Thus, despite the larger variability observed in these metrics, we can confident that the increase can be attributed to the effect of fatigue and change in NMF and not the variability in measurement. The CD has previously been observed to be the most sensitive CMJ variable when monitoring NMF across a season in professional ice hockey [33], with reductions also shown immediately post- and match day minus three in male academy and senior soccer players [11,14,34]. However, the results of the present study contrast these findings with meaningful increases in CD and TTTO pre- to post-international tournament, likely indicating a fatigue response. The larger CD and TTTO, resulting in a compliant strategy, likely reduced peak braking forces, which were not observed within the present study. The greater displacement could result in a greater downwards velocity and therefore, momentum requiring greater deceleration demands. However, as decreases were also observed in ARBf it is likely that athletes adopted a tentative approach to the unweighting phase, and not fully unweighting by potentially applying a braking or deceleration force, which could be indicative of reduced NMF. The ratio mRSI metric is indicative of CMJ efficiency, only pre- to post-international tournament was efficiency shown to decrease, requiring a greater duration to achieve the outcome. However, as is essential with all ratio metrics observations of the constituent parts should also be made as changes to either could affect the mRSI, in the example of mRSI both JH and TTTO should also be monitored.

Monitoring of NMF has become common place within elite sport practises, most commonly within soccer with observations made of single matches [11,14,34]. To the authors knowledge, the present study is the first study to the authors knowledge to track CMJ performance across a short international tournament, with multiple fixtures. Reductions in SW have commonly been reported, which is consistent with the present study, which has been attributed to water loss and/or glycogen depletion although this needs further investigation within the present cohort 35. Within soccer, large depletions in glycogen stores have been observed from pre- to post-match play, with the relative glycogen depletion being observed at levels (~250 mmol·kg^{-1}) that have been associated with reduced high intensity activity performance and reduced exercise tolerance [36-38]. This could be integral to present study, with the larger decrease in SW was observed from pre- to post-three matches, especially as this increased greatest during the match congestion on the second day of competition before the culmination of the tournament at the finals. This firstly could present a novel concept in the way of microdosed match congestion, with multiple matches over shorter periods of 3-4 days with longer durations between competitions (this would be similar to what is experienced within international rugby sevens). This contrasts traditional definitions of match congestion, where multiple fixtures (2-3 matches) are played within 7-10 days, typically occurring within soccer [39].This highlights the need for specific nutritional strategies for Sixes lacrosse to cope with these microdosed demands, including hydration and fuelling, with male soccer players who are typically hypo-hydrated for performance [40], this observation could be consistent with Sixes lacrosse players although this requires investigation. However, monitoring and coaching of hydration status and strategies could be similarly useful to Sixes lacrosse if a similar approach is adopted to what has been adopted in soccer 40. Within 12 hours, body mass can return to baseline (as observed between match day 1 and match day 2 within the present study), female NCAA division 1 soccer players body mass was not significantly lower 12 hours post-match play, although the authors did not observe body mass immediately post, it could be postulated that if similar decreases were present post-match refuelling strategies can offset any reductions in muscle glycogen. Therefore, appropriate nutritional strategies require identification to ensure they can be applied in international tournament settings.

This study is not without limitations, the CMJ is a variable multi-joint movement and typical movement variability could impact on the ability to identify changes in jump performance due to impaired NMF [41]. Specifically, the strategy metric (CD and TTTO) and outcome measure of mRSI had the lowest variability of any of the CMJ metrics observed (Table 3). It is worth noting that the interpretation of the CV% is based on the upper bound 95% CI, which provides the worst-case scenario for the variability, with it likely to fall between the upper and lower bound 95% CIs. However, performing sufficient familiarisation, consistent implementation of CMJ assessments and making observations of multiple metrics associated with jump performance could offset this variability, as supported by Spencer and colleagues [14]. The purpose of the present study was to identify if there is a change in CMJ performance due to participating in international Sixes lacrosse. Future research should attempt to explain what drives the changes in CMJ metrics through more robust statistical approaches, such as a linear regression. This would provide insights into what external load (or internal load if collected), drives the change in CMJ performance and thus NMF. With the increased availability of force plates and other force assessment technology (i.e. strain gauges), other performance assessments could provide further insights in to localised fatigue which could be indicative of injury risk. Isometric knee flexion assessments have consistently shown reductions in absolute force and rapid force generating capabilities following fatiguing activity (i.e. match play, simulated match play or repeated sprint performance) potentially increasing the risk of hamstring strain injury [42-47]. Therefore, dynamic and static isometric assessments could form part of a monitoring protocol to ensure adequate sensitivity to detect deviations in both global and local NMF which could aid practitioners in planning recovery strategies.

CONCLUSIONS

The findings of the present study support the tracking of multiple CMJ metrics, as looking at jump outcome alone could be misleading. Therefore, practitioners are advised to use the PODS system to observe changes in the person (system weight or mass), outcome (JH and JM), drivers (ARBF and ARPF) and strategy (CD and TTTO), which can provide an objective view of CMJ performance and potentially greater ability to detect changes in NMF. With a microdosed match congestion present within international Sixes lacrosse and rugby sevens, specific monitoring protocols become essential to ensure optimal sports performance can be achieved. Given the increased importance of Sixes lacrosse and with Olympic inclusion it becomes paramount that practitioners, who have only been working with this recently developed format for a maximum of four years need to quickly upskill. Future research is required to ensure optimal processes of fatigue monitoring, including test selection and administration, as well as determining the primary mechanism of fatigue (metabolic or neuromuscular) to ensure recovery and nutritional strategies can be applied.

CONFLICTS OF INTEREST

There are no conflicting relationships or activities.

FUNDING

This study received no specific funding in order to be completed.

ETHICAL APPROVAL

This study was approved by the Ethics Review Board of University of Salford (ID number 9603) and conducted in accordance with the Declaration of Helsinki (2013). All players provided written informed consent and were ensured the anonymity of data and identities.

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