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Running title: Neuromuscular, physiological and perceptual responses to elite netball

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Neuromuscular, physiological and perceptual responses to an elite netball tournament

Abstract

To examine responses to an International netball tournament, female athletes (*n*=11) played three matches over consecutive days. External (accelerometry) and internal (heart rate; HR, session; sRPE, and differential; dRPE, rating of perceived exertion) load measures quantified match intensity. On match-day mornings, and three days after match three, well-being (brief assessment of mood; BAM+), biochemical (creatine kinase concentration; CK), neuromuscular (jump height; JH, peak power output; PPO) and endocrine function (salivary cortisol; C, testosterone; T, concentrations) were assessed. External load was similar between matches whereas dRPE and sRPE was greatest for match three. Following match one, CK increased, whereas BAM+, JH, C and T decreased. Following two matches, BAM+, PPO, and T decreased with CK increasing versus baseline. Following consecutive matches, CK (likely moderate; 27.9% ± 19.5%) and C (possibly moderate; 43.3% ± 46.8%) increased, whilst BAM+ (possibly moderate; -20.6% ± 24.4%) decreased. Three days post-tournament BAM+, T, PPO, and JH decreased. Mid-court elicited higher mean HR (possibly moderate; 3.7% ± 3.8%), internal and external intensities (possibly very large; 85.7% ± 49.6%) compared with goal-based positions. Consecutive matches revealed a dose-response relationship for well-being and physiological function; a response evident three days post-tournament.

Keywords: recovery; monitoring; load; team sport; readiness to train

Introduction

Whilst several studies have reported the movement demands of elite netball in recent years (Bailey, Gastin, Mackey, & Dwyer, 2017; Fox, Spittle, Otago, & Saunders, 2013; Young, Gastin, Sanders, Mackey, & Dwyer, 2016), to date no studies have profiled the physiological responses to elite level tournament match-play. Indeed, only three studies have reported the movement demands of elite netball, one by use of notational analysis (Fox et al., 2013) and two by accelerometry (Bailey et al., 2017; Young et al., 2016). Goal defence (GD), goalkeeper (GK) and goal shooter (GS) positions were reported to perform at the the lowest playing intensities and highest proportions of match time spent in the low-intensity zones when compared to players occupying wing attack (WA), wing defence (WD), centre (C), and goal attack (GA) positions (Young et al., 2016). Additionally, Bailey et al., (2017) reported the accelerometer-based loads associated with typical activities, reporting off-ball guarding to elicit the highest load per instance, whilst jogging accumulated the greatest load across a match.

At present, a single study has reported the responses to an isolated match reporting a reduction in perception of fatigue and neuromuscular performance immediately and 24 h after an 80 min elite level match, returning to baseline 36 h later (Wood, Kelly, & Gabbett, 2013). Many tournaments require teams to play up to eight matches in 10 days, therefore, the demands are not limited to that of a single match, rather the ability to perform and recover over a series of days. Findings of previous studies reporting the neuromuscular and perceptual recovery profiles (Wood et al., 2013) may be limited by match duration (80 min compared to 60 min for International matches), small sample size (*n*=6) and single match design as opposed to that of a tournament, leading to an underestimation of the responses to tournament match-play. Recent reports of match demands have differed (Fox et al., 2013) to previous reports in elite players (Otago, 1983), as such recent rule changes (January 2016), intended to reduce stoppages and increase the speed and intensity of match-play, may have compromised the application of previous literature regarding the demands and responses to netball match-play. Limited information exists regarding the external loads of professional netball, (Bailey et al., 2017; Young et al., 2016) and no studies have examined the physiological demands and responses to either a single or multiple instances of International-standard netball match-play. A deeper understanding of the movement patterns, coupled with physiological demands, can allow effective training to be prescribed to optimise adaptation and performance, however this information is currently limited (Bailey et al., 2017). Therefore, the purpose of this study was to examine the physiological, neuromuscular, endocrine and perceptual responses to an International netball tournament as well as the physiological demands of International-standard netball.

Methods

This observational study examined the response to a netball tournament performed over three consecutive days. Matches commenced at 19:00, 15:00 and 15:00 h on days one to three, respectively. On the morning of each match (~07:30 h), and three days (approximately 62 h) after the final match (~07:30 h), scores for perceived well-being (adapted brief assessment of mood+; BAM+), and samples of whole blood (Creatine Kinase concentration; CK) and saliva (cortisol; C and testosterone: T concentrations) were collected, and countermovement jump testing performed. Match intensity was quantified using both internal (heart rate telemetry) and external (accelerometry) load metrics. Following the match, players individually recorded session (sRPE: Foster et al., 2001) and differential ratings of perceived exertion (dRPE: Weston, Siegler, Bahnert, McBrien, & Lovell, 2015) using a numerically blinded CR100® scale via an Android tablet. These values were recorded during the cool down period, ~15 min after match-play.

Eleven female players (age: 25 ± 4 years; mass: 71.8 ± 7.8 kg; height: 1.8 ± 0.1 m) from an International netball team were recruited. Players were assigned according to positions to goal-based (*n=2,* GS and GK) and mid-court (*n*=9, GD, WD, WA, C and GA) groups based on court movement restrictions. This study included an International tournament played at the end of the 2016 domestic season. As such, all players had competed weekly in the British Super League (highest netball league in Britain) and were engaged in full-time training (strength, speed, endurance and netball-specific training sessions four to six times per week) as part of their club's performance preparation program. Five players used no form of hormonal contraceptive and players were requested to self-monitor menstrual cycles and days of contraceptive consumption. Subsequent analyses revealed no bias in hormonal markers as a function of contraceptive use. This study was approved by the Swansea University ethics committee, players were informed of the benefits and risks of the investigation before signing informed consent forms and completing health screening and were made aware that all material would be anonymised. All mandatory health and safety procedures were complied with in completing this research study.

Players completed BAM+ which is correlated to high-intensity match activity, and is sensitive to physiological responses following elite team sport match-play

(Shearer et al., 2017). Using an Android tablet (Iconia One 7 B1-750, Taipei, Taiwan: Acer inc), a series of questions was answered with a 100 mm visual analogue scale anchored with “not at all [0]” and “extremely [100]”. An overall recovery score was generated by subtracting the mean score of negative related items from the mean score of the positively related questions using Equation 1: (Shearer et al., 2017)

Equation 1: (Alertness + sleep quality + confidence + motivation) /4 - (Anger + confusion + tension + depression + fatigue + muscle soreness)/6.

For salivary hormone analysis, players were instructed to avoid eating food or drinking fluids other than water after waking to avoid contaminating saliva samples. Prior to breakfast, a two ml sample of saliva was collected via passive drool (Crewther et al., 2013) into sterile containers, with samples subsequently stored at -70°C until assay. After thawing and centrifugation (2000 revolutions·min^{-1} for 10 min), the samples were analysed in duplicate for T and C using commercial kits (Salimetrics, LLC, State College, PA, USA). The minimum detection limit for the testosterone assay was 6.1 pg·ml^{-1}, with interassay coefficient of variation (CV) <10%. The cortisol assay had a detection limit of 0.12 ng·ml^{-1} with interassay CV <7%. Samples for each player were assayed in the same plate to eliminate inter-assay variability.

Whole blood CK concentrations were measured via capillary blood (120 µl) being sampled from the fingertip and stored on ice in EDTA prepared collection tubes (Microvette 500, Sarstedt, Numbrecht, Germany) before being centrifuged at 3000 revolutions·min^{-1} for 10 min (Labofuge 400R; Kendro Laboratories, Langenselbold, Germany). Plasma samples were then stored at −70°C before being analysed for CK concentration using commercially available kits (CK-NAC, ABX Diagnostics, Northampton, United Kingdom) on a spectrophotometer (Cobas Mira, ABX Diagnostics, Northampton, United Kingdom). Samples were measured in duplicate (CV=3%) and recorded as a mean.

A portable force platform with built-in charge amplifier (Kistler type 92866AA, Kistler Instruments Ltd., Farnborough, UK) measured the ground reaction force-time history of countermovement jumps. A sample rate of 1000 Hz was used, and the platform's calibration was confirmed prior to testing. Power (CV=2.4%) and jump height (JH; calculated from takeoff velocity; CV=3.4%) was calculated using previously established procedures (Owen et al., 2014; West et al., 2011) and have been reported to be sensitive to changes following competitive matches (Russell et al., 2015; West et al., 2014). Players performed a standardised warm up before jumping, placed hands on hips throughout the jump, and performed two jumps at each time-point with the best jump taken as the highest peak power output (PPO) and used in subsequent analyses.

External load was quantified by use of a microtechnology unit (Catapult S5, Catapult, Innovations, Leeds, UK) housing an in-built tri-axial accelerometer sampling at 100 Hz. Players wore a custom-made vest (Catapult Innovations, Leeds, UK) in which units were held in place vertically on the upper back to minimise movement. Data were downloaded using the manufacturer's software (Catapult sprint 5.1, Catapult Innovations, Leeds, UK), analysed for player-load for each quarter, excluding breaks between quarters, with data represented as external load intensity (AU·min^{-1}). Data was pooled and reported for each position rather than individual players, such that for every match each position would have a single external load intensity for each quarter. Player-load has been reported to be a valid and reliable method (Barrett, Midgley, & Lovell, 2014; Boyd, Ball, & Aughey, 2011) of measuring activities performed in team sports movements, with high within and between-device (CV~1%: Boyd et al., 2011) reliability and has been widely used in team sports (Luteberget & Spencer, 2017; Polgaze, Dawson, Hiscock, & Peeling, 2015) including netball (Chandler, Pinder, Curran, & Gabbett, 2014; Young et al., 2016) with detailed calculations described previously (Barrett et al., 2014). Players wore heart rate (HR) monitors (Polar Team System 2, Polar Electro, Warwick, UK) throughout matches, with HR recorded at beat-to-beat intervals. Data was downloaded and analysed for each quarter, excluding breaks between quarters, and only whilst the player was on-court, using the Polar team system software (Polar Team 2, Polar Electro, Warwick, UK). HR data was reported for each player and associated to the position which had been played.

Following each match, players recorded sRPE along with indices of dRPE including ratings for breathlessness (RPE-B), leg muscle exertion (RPE-L), upper body muscle exertion (RPE-U) and cognitive/technical demands (RPE-T) (Weston et al., 2015). Ratings were provided using a numerically blinded CR100® scale with verbal anchors using a bespoke application on an Android tablet. dRPE provides a detailed quantification of internal load during team sport activities (McLaren, Smith, Spears, & Weston, 2017), is a sensitive marker of match exertion (Weston et al., 2015) and distinguishes between different areas of effort (McLaren et al., 2017; Weston et al., 2015). Players must have performed a minimum of one quarter for sRPE and dRPE to be included in subsequent analyses.

Data are reported as mean difference ± 90% confidence limits unless otherwise stated. Visual inspection of the residual plots revealed evidence of heteroscedasticity; therefore, except for sRPE, dRPE, BAM+ and HR, analyses were performed on log transformed data. Separate mixed linear mixed models (SPSS v.24, Armonk, NY: IBM Corp) were used to examine the effect of tournament match-play on measures of physical exertion (external load, HR, sRPE, dRPE) and, thereafter, the effect of playing position on match physical exertion, and, the effects of tournament match-play on the players' neuromuscular, physiological and perceptual responses (PPO, JH, CK, T, C). In these models, match (match 1, match 2, match 3), playing position (mid-court, goal-based) and time (day 1, day 2, day 3, 3 days post), respectively were entered as the fixed effects. In all models, players were included as a random effect with random intercept to account for the dependency that arises from a hierarchical data structure such as ours (i.e., repeated measurements from the same players). From here, a custom-made spreadsheet (Hopkins, 2007) was used to determine magnitude based inferences (Batterham & Hopkins, 2006) for all differences, with inferences based on standardised thresholds for small, moderate, large and very large differences of 0.2, 0.6, 1.2 and 2.0 of the pooled between-subject standard deviations (SD) (Hopkins, Marshall, Batterham, & Hanin, 2009). The chance of the difference being substantial or trivial was interpreted using the following scale: 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely (Batterham & Hopkins, 2006). Uncertainty in all estimates is expressed via 90% confidence limits and the magnitude of effects assessed mechanistically, whereby if the confidence limits overlapped the thresholds for the smallest worthwhile positive and negative effects, effects were deemed unclear (Hopkins et al., 2009).

Results

Match data are presented in Table 1. Mean playing time for players across the three matches was 119.8 min (± 48.5 min; ± SD) and outcomes included two wins and a loss for matches one to three respectively. In response to a single netball match, from day one to day two, CK (likely very large; 72.6% ± 26.4%) and fatigue (likely small; 56.2% ± 46.0%) increased, whilst motivation (likely moderate; -19.5% ± 14.3%), BAM+ (likely moderate; -27.9% ± 17.6%), sleep quality (possibly moderate: -16.3% ± 15.6%), C (likely small; -27.4% ± 23.7%), T (possibly small; -10.8% ± 10.8%) and JH (possibly small; -4.0% ± 2.5%) decreased, with a possible trivial difference for PPO and unclear difference for soreness (Table 2). Following two netball matches, from day one to day three, CK (most likely very large; 120.8% ± 33.7%), fatigue (possibly large; 146.9% ± 46.0%) and soreness (possibly moderate; 57.7% ± 37.9%) increased, whilst BAM+ (likely large; -42.8 ± 17.6%), motivation (likely moderate; -20.6% ± 14.3%), sleep quality (possibly moderate; -30.8% ± 15.6%), T (possibly small; -8.7% ± 11.0%) and PPO (possibly small; -3.3% ± 1.7%) decreased, with a possible trivial difference for JH and most likely trivial difference for C. Following the performance of two consecutive matches, from day two to three, CK (likely moderate; 27.9% ± 19.5%), fatigue (likely moderate; 58.1% ± 29.5%), soreness (possible moderate; 49.6% ± 36.0%) and C (possibly moderate; 43.3% ± 46.8%) increased whilst BAM+ (possibly moderate; -20.6% ± 24.4%) and sleep quality (possibly moderate; -17.3% ± 18.6%) decreased, with an unclear difference for T and motivation, and likely trivial difference for JH and PPO. Three days post-tournament BAM+ (likely very large; -57.5% ± 20.5%), sleep quality (likely large; -38.7% ± 18.1%), motivation (likely moderate; -24.3% ± 16.6%), PPO (likely small; -4.2% ± 1.9%), JH (possibly small; -3.9% ± 2.8%) and T (possibly small; -10.0% ± 12.7%) decreased, whilst fatigue increased (very likely moderate; 127.2% ± 53.6%) compared to day one, with unclear differences for C, CK and soreness.

*****Table 1 about here*****

*****Table 2 about here*****

Greater mean HR for match one occurred relative to match two (possibly small; 1.2% ± 1.2.0%). Likely trivial differences were observed for external load intensity and unclear differences for sRPE and dRPE variables. For match three versus one for RPE-B (likely small; 20.1% ± 25.4%), RPE-L (possibly small; 18.2% ± 24.5%), RPE-U (possibly small; 18.1% ± 22.4%) and RPE-T (possibly moderate; 23.2% ± 19.8%), greater values were observed. A possible trivial difference existed for external load intensity and unclear differences for sRPE and mean HR. Match three produced greater sRPE (likely small; 21.7% ± 27.4%), RPE-B (possibly moderate; 32.0% ± 26.7%), RPE-L (possibly moderate; 30.8% ± 25.9%), RPE-U (likely small; 30.6% ± 23.7%), RPE-T (possibly moderate; 27.1% ± 20.2%) and mean HR (possibly small; 1.1% ± 2.0%) versus match two. There was a possible trivial difference for external load intensity.

Overall, mid-court positions performed at a greater external load intensity (possibly very large; 85.7% ± 49.6%), mean HR (possibly moderate; 3.7% ± 3.8%) (Table

3), and reported higher sRPE (possibly moderate; 40.7% ± 40.0%), RPE-B (likely moderate; 55.9% ± 51.9%), RPE-L (possibly large; 79.3% ± 48.1%), RPE-U (possibly moderate; 47.2% ± 54.9%) and RPE-T (possibly moderate; 36.9% ± 36.7%) compared to goal-based positions (Table 4).

*****Table 3 about here*****

*****Table 4 about here*****

Discussion

The aims of this study were to characterise the physiological, neuromuscular, endocrine and perceptual responses to an International tournament and to identify the position-specific demands of International netball. The primary findings were that the performance of both a single, and multiple matches resulted in a varied recovery profile, with greater perturbations in perceived well-being and physiological function following consecutive matches, and fatigue evident up to three days post-tournament. Additionally, mid-court positions performed at greater internal and external load intensity compared to goal-based positions.

Across the tournament, CK, reported to be indicative of skeletal muscle damage (Cunniffe et al., 2010), accumulated before returning to baseline thereafter. Whilst there are no reports in netball, investigations in other team sports have reported peak values occurring 24 h post-match, remaining elevated for females for up to 69 h (Andersson et al., 2008). Three days post-tournament, CK and perceived soreness had returned to baseline, however neuromuscular performance and T concentrations remained suppressed. This may suggest that neuromuscular performance is impacted by T concentration rather than muscle damage, that CK is not sensitive to detect changes in muscle damage, or that various markers of fatigue collectively interact.

Following the performance of a single match, T was reduced, and remained reduced until three days post-tournament, whilst C decreased following the first match, then returned and remained at baseline following the second match. Testosterone concentration is associated with enhanced neuromuscular performance (Cook, Kilduff, Crewther, Beaven, & West, 2014), decision making, behaviour, contractile signalling (Crewther, Cook, Cardinale, & Weatherby, 2011), motivation (Cook, Kilduff, & Crewther, 2018) and performance (Crewther et al., 2013). A reduction, as seen in the present study, may have negatively affected one or more of these reported associations, with a resultant impact upon performance. The recovery of C following two matches may suggest a varied anticipatory response with a greater anticipatory rise prior to the first and final match (higher ranked opponent for the final match). However, alternatively the late commencement (19:00 h compared to 15:00 h) of match one may have negatively affected post-match processes and recovery. Menstrual phase and hormonal contraceptive use were not controlled for in the present study, however no difference was found in basal T between hormonal contraceptive users and non-users. Additionally, recent reports highlight only a difference in magnitude of T response to a stimulus, rather than the response itself, and no impact upon performance with hormonal contraceptive use (Cook et al., 2018).

This is the first study to characterise playing demands during an International tournament reporting external load, perceived effort and HR. Internal and external load was greater for mid-court compared to goal-based positions (Table 3). Greater external load intensity for mid-court positions has been previously reported in professional netball (Fox et al., 2013; Young et al., 2016), and is likely due to court movement restrictions resulting in a higher active time (Fox et al., 2013), time spent in high-intensity zones (Young et al., 2016) and type of on and off-ball locomotor and non-locomotor activity (Bailey et al., 2017). Collectively, this suggests that players should not only be conditioned for the position specific movement demands, as previously reported, but also the different physiological and type of effort (as indicated by dRPE) experienced during International match-play. Both sRPE and dRPE can be used by conditioning staff to guide the individualisation of the training stimulus to the positional demands. As markers of fatigue were further reduced following a greater number of consecutive matches, training should aim to replicate these demands to minimise this disturbance, especially when considering that some International tournaments are up to twice as long as in the present study. Unlike perceptual and endocrine responses, neuromuscular performance was not further reduced following consecutive matches. Perceptual markers could therefore be considered as a simple monitoring tool to identify sufficient training load to replicate the fatiguing consequences associated with International netball. Sleep quality was negatively affected following a single, and to a greater extent following consecutive matches, a consideration for coaching and support staff, as sleep has been reported to be vital for recovery (Halson, 2008). Three days post-tournament, when players commenced training, perceived well-being, sleep quality, T concentration and neuromuscular function were reduced, suggesting longer recovery is required than anticipated by conditioning staff.

Conclusion

This is the first study to report the physiological demands of and responses to an International netball tournament, providing vital information for International coaches and conditioning coaches. Markers of fatigue increased following the performance of a single match, whilst markers of muscle damage and perceived well-being were further affected following consecutive matches. A varied recovery profile was apparent as recovery to baseline of all variables examined did not occur 62 h post-tournament. Mid-court positions performed at higher external and internal intensities compared to goal-based positions, an important consideration for conditioning staff in order to individualise training to positional specific demands.

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Disclosure of interest

The authors report no conflict of interest.

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