Full title: The neuromuscular, physiological, endocrine and perceptual responses to different training session orders in International female netball players.

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The neuromuscular, physiological, endocrine and perceptual responses to different training session orders in International female netball players.

The 20 h responses of International female netball players to training days requiring two sessions (netball and strength, separated by two hours) ordered alternatively were examined. Eleven players completed strength followed by netball training two hours later (STR-NET), with the order reversed (NET-STR) on a separate day. Well-being, neuromuscular performance (jump height [JH], peak power output [PPO], peak velocity [PV]) and endocrine function (testosterone, cortisol concentrations) were measured before sessions one (PreS1) and two (PreS2), immediately after sessions one (IPS1) and two (IPS2), and 20 h post session one (20P). Session and differential ratings of perceived exertion (upper-body, cognitive/technical [RPE-T], lower-body, breathlessness), were collected, and accelerometry and heart rate measured netball load. Identification of clear between-order differences were based on the nonoverlap of the 95% confidence interval (95%CI) for mean differences relative to baseline. Compared to PreS1, greater increases in JH (percentage difference between trials; 95%CI: 9%; 4 to 14%), PPO (5%; 2 to 8%), PV (3%; 1 to 5%) and cortisol concentration (45%; 1 to 88%), and a greater decrease for testosterone/cortisol ratio (-35%; -72 to -2%) occurred at PreS2 in NET-STR. At 20P, greater decreases in JH (10%; 5 to 15%), PPO (4%; 1 to 8%) and PV (4%; 2 to 6%) were observed following STR-NET. No differences existed for well-being, whilst RPE-T was greater (15 AU; 3 to 26 AU) for strength training during NET-STR. Session order influenced neuromuscular and endocrine responses in International female netball players, highlighting session ordering as a key consideration when planning training.

Keywords: Team-sport; Hormonal; Recovery; Muscle damage

Introduction

Netball in an intermittent team-sport with court movement restrictions yielding unique position-specific movement and playing demands (Young, Gastin, Sanders, Mackey, & Dwyer, 2016). This results in an intense, intermittent activity profile involving short explosive movements, interspersed with short recovery periods (Fox, Spittle, Otago, & Saunders, 2013). Mid-court positions perform at higher internal and external intensities than goal-based positions (Birdsey et al., 2019), whilst each position performs a unique set of locomotor and non-locomotor activities which contribute to the total load (Bailey, Gastin, Mackey, & Dwyer, 2017). In order to prepare for these demands, players often perform multiple training sessions within a day (Simpson, Jenkins, Scanlan, & Kelly, 2020). This includes technical on-court training, on and off-court conditioning, in addition to strength training (Chandler, Pinder, Curran, & Gabb, 2014; Simpson et al., 2020) in order to develop physical, technical and tactical aspects of match-play. As players perform training to improve unique aspects related to netball performance (Young et al., 2016) the applicability of findings from other team-sports may be limited. It is therefore imperative that responses to netball-specific training are fully understood, however, this is currently lacking.

To overload specific variables that optimise physical performance preparation, professional team-sport athletes often perform multiple training sessions per day (Johnston et al., 2017), including technical, speed, aerobic and strength-focused activities. Whilst some studies report positive adaptations to the performance of multiple training sessions, or training aims, in a concurrent training paradigm (García-Pallarés, Sánchez-Medina, Carrasco, Díaz, & Izquierdo, 2009), a reduced training effect (Jones, Howatson, Russell, & French, 2016), proposed due to a failure to maintain training performance (Leveritt, Abernethy, Barry, & Logan, 1999) and compromised molecular signalling (Hawley, 2009), may also occur. The physiological responses to, and fatigue experienced after, exercise is specific to the intensity (Seiler, Haugen, & Kuffel, 2007), volume (Lepers, Maffiuletti, Rochette, Brugniaux, & Millet, 2002) and mode (Sparkes et al., 2020) and can persist for several days (Brownstein et al., 2017). Therefore, the ordering of training sessions within a concurrent training paradigm is important when determining subsequent training performance (Johnston et al., 2017) and ensuing adaptations (Jones et al., 2016).

Prior exercise influences subsequent physiological and neuromuscular function (Mcgowan, Pyne, Thompson, Raglin, & Rattray, 2017; Russell et al., 2016), as well as performance (Johnston et al., 2017). Higher afternoon core temperature has been reported following morning swimming exercise, with an associated improvement in performance (Mcgowan et al., 2017); likely due to increased muscle temperatures and concomitant positive effects on neuromuscular function (West, Cook, Beaven, & Kilduff, 2014). Morning exercise can also attenuate the circadian rhythm associated decline in testosterone concentration and lead to improved afternoon neuromuscular performance (Russell et al., 2016). Whilst this has typically been over a longer time period (e.g. 5-6 h between training sessions), speed training performance may be enhanced when preceded by strength training two hours prior (Johnston et al., 2017). When repeated, this enhanced training performance may result in greater adaptive response and improved competitive performance (García-Pallarés et al., 2009). However, as the performance of prior training may impair subsequent performance (Doma & Deakin, 2013) and strength development (Jones et al., 2016), it is clear that the understanding of these responses is important when targeting specific adaptations (García-Pallarés et al., 2009).

Netball has unique movement and playing demands, and as physiological responses are influenced by many factors (Lepers et al., 2002; Seiler et al., 2007; Sparkes et al., 2020), it is vital that responses to netball-specific training are fully understood. In preparing for the demands of International netball, it is commonplace to perform multiple within-day training sessions, however limited literature has identified if session order affects responses both during and after training sessions; data which has implications for programming. An understanding of the acute post-training fatigue and recovery responses to session order can allow the coach to effectively plan training to optimise adaptation. Therefore, the purpose of this study was to compare the physiological, endocrine and perceptual responses to a training day consisting of both strength and netball-training sessions performed two hours apart, executed as both strength training followed by netball training and netball training followed by strength training.

Material and Methods

Participants

Eleven female netball players (age: 21 ± 1 years, mass: 76.8 ± 10.2 kg, height: 1.81 ± 0.07 m) from an U21 and senior International netball team were recruited for this study. All players had been members of the National World Class Performance programme for a minimum of one year, played for the U21 or Senior National team and were experienced in all forms of training and competition, including strength training. This study was performed during the 2018/19 pre-season period, after a four-week period of prescribed training as part of the squad's performance programme. This consisted of two sessions per day of strength, speed, endurance and technical netball-training sessions, performed in various combinations and orders, four days per week, to ensure that players were fully conditioned to the training demands involved in this study. Although players were instructed to monitor their menstrual cycle and provided information regarding hormonal contraceptive use and menstrual cycle phase, this was not controlled for. Institutional ethical approval was granted (Swansea University ethics committee; approval number 2018-064) prior to data collection and participant recruitment.

Players were informed of the purposes and procedures of the investigation prior to signing an informed consent document and health screening questionnaire and were made aware that all material would be anonymised. All mandatory health and safety procedures were complied with in completing this research study.

Design

This repeated measures cross-over study was conducted over a nine-day period consisting of the completion of regularly performed netball and strength-training sessions. On a given training day, players performed two training sessions, separated by two hours, with measures collected prior to training sessions one (PreS1) and two (PreS2), immediately post sessions one (IPS1) and two (IPS1) and 20 h after session one (20P) (Figure 1). Measures were collected within 15 minutes of commencing or completing each training session. Two training days were performed on separate occasions, initially as strength training followed by netball training (STR-NET) and seven days later as netball training followed by strength training (NET-STR).

*****INSERT FIGURE 1 NEAR HERE*****

Measures included collection of saliva samples (testosterone, cortisol concentrations), recording of perceived mood (adapted brief assessment of mood [BAM+]; Shearer et al., 2017), and countermovement jump (peak power output [PPO], PPO relative to mass [PPOrel], jump height [JH], peak velocity [PV]) testing. Netball loads were quantified externally (accelerometry) and internally (heart rate [HR], session ratings of perceived exertion [sRPE], differential ratings of perceived exertion [dRPE]). Testing was performed on the first training day of the week (following a rest day) and training prescribed to players throughout this period was the same prior to both testing days.

Players reported to the first training session of the day at approximately 12:30 h to perform a strength-training session and were instructed to eat and drink to prepare as usual for training, as prescribed by the team nutritionist. Following completion of the training session, players had a two-hour break, during which time they ate and drank following the direction of the team nutritionist, to recover from, and prepare for, the second training session of the day, which was an on-court technical netball-training session. Players reported the following morning at 08:00 h, approximately 20 h post training session one (20P), for testing, having prepared nutritionally as if they were attending another training session. Due to the nature of working with an International netball-team, and numbers required for training, no randomisation took place. As such, all players performed training in the same order, with strength training followed by netball training performed first (STR-NET), and the reverse order performed the following week (NET-STR). Both training days involved the same training sessions, same content, with only the order differing between trials.

Netball-training session

The on-court netball-training session had a duration of 107 min (± 2.8 min). This was a routinely performed session by the team, which had featured regularly in the pre-season period, with the aim of developing technical skills, movement patterns and decision making. Initially, players performed a court-based warm-up of 19.7 min (± 0.9 min), consisting of team-based exercises involving changes of direction, short sprints, dynamic stretching, ball skills and netball specific movements. Four technical drills were then performed, focussed around creating and using options. This progressed from one on one in a small square (approximately three by three metres) to two on two in a larger space (approximately four by four metres) aiming to create space to both make and receive a pass from a feeder outside the square. Next, this was performed in the goal circle, with the aiming of scoring, with the final drill involving two attackers taking the ball past two defenders in each third, before passing the ball to a goal shooter. For both the STR-NET and NET-STR trials, the same session was performed.

Strength-training session

The strength-training session had a duration of 58.8 min (± 2.5 min) and consisted of warm-up exercises, followed by three sets of six repetitions of two upper-body (bench press, supine row) and two lower-body (a combination of reverse lunge, Romanian dead lift, leg press) exercises. This was performed at 85% of one-repetition maximum with four minutes recovery between sets, had been regularly performed by players throughout this training period and was repeated across both trials.

Mood

Mood was recorded by use of a modified version of the brief assessment of mood (BAM+; Shearer et al., 2017). Using a bespoke application on an Android tablet (Iconia One 7 B1-750, Taipei, Taiwan: Acer inc), a series of 10 questions was answered one at a time with a 100 mm visual analogue scale anchored with "not at all" and "extremely" at 0 and 100 respectively, to record how players felt at that moment in time. The questions assessed: alertness, sleep quality, confidence, motivation, anger, confusion, tension, depression, fatigue and muscle soreness, and were written as, for example, "how angry do you feel?". An overall mood score was calculated by subtracting the mean score of negatively related items from the mean score of positively related items using the equation below (Shearer et al., 2017):

Mood score = (Alertness+sleep quality+confidence+motivation)/4 - (Anger+confusion+ tension+depression+fatigue+muscle soreness)/6

This method of calculating mood has acceptable internal consistency (cronbach alpha score of 0.65 to 0.82; Shearer et al., 2017) and is moderately correlated to high intensity match activity (Shearer et al., 2017). Additionally, it is sensitive to physiological responses following competition (Shearer et al., 2017) and training (Sparkes et al., 2020) in elite team-sport players, and following netball match-play (Birdsey et al., 2019). Individual scores for perceived muscle soreness, fatigue and motivation were also assessed, as these markers are sensitive to netball match-play (Birdsey et al., 2019), to soccer training (Brownstein et al., 2017) and may impact athletic performance (Rowsell, Coutts, Reaburn, & Hill-Haas, 2011).

Endocrine function

For salivary hormone analysis, players were instructed to avoid eating food and drinking fluids other than water for 60 min prior to sampling to avoid contamination of samples. Two millilitres of saliva was collected via passive drool (Crewther et al., 2013) in to sterile containers with samples subsequently stored at -80°C until assay, and analysed for testosterone and cortisol concentrations using commercially available kits (Salimetrics, LLC, State College, PA, USA). The minimum detection limit for the testosterone assay was 6.1 $pg \cdot ml^{-1}$, with inter-assay coefficient of variation (CV) of 0.4%. The cortisol assay had a detection limit of 0.12 $ng \cdot ml^{-1}$ (CV=3.8%). Samples for each participant were assayed in the same plate to eliminate inter-assay variability.

Neuromuscular performance

To measure ground reaction force time history of countermovement jumps a portable force platform with built-in charge amplifier (type 92866AA, Kistler Instruments Ltd., Farnborough, UK) was used with a sample rate of 1000 Hz, and calibration confirmed pre-testing. Jump height calculated from take-off velocity (CV=3.4%) and power (CV=2.4%) were calculated using previously established procedures (Owen, Watkins, Kilduff, Bevan, & Bennett, 2014), along with PV which has low variability (CV=2.5%; Gathercole, Sporer, Stellingwerff, & Sleivert, 2015). Prior to countermovement jump testing players performed a standardised warm-up (two sets of 10 repetitions of the lunge, side lunge and squat exercises, followed by two practice countermovement jumps), apart from immediately post-training (IPS1, IPS2), at which point one practice jump was performed only. Countermovement jump testing was performed within 15 minutes of commencing and within five minutes of completing each training session. Players performed two jumps, with the best jump used in subsequent analyses, were instructed to jump as high and as fast as possible, to keep hands on hips throughout the jump, and were familiar with this testing procedure.

Exercise intensity

Activity during netball was recorded using commercially available units (Catapult S5, Catapult Innovations, Leeds, UK) housing a tri-axial accelerometer sampling at a rate of 100 Hz. Players wore a custom-made vest (Catapult Innovations, Leeds, UK) to minimise movement artefacts, in which the units were held in place vertically in the centre of the upper back, slightly superior to the shoulder blades (Barrett, Midgley, & Lovell, 2014). Players used the same unit for all netball-training sessions in order to avoid inter-device variability. Data were downloaded using the manufacturer's software (Catapult sprint 5.1, Catapult Innovations, Leeds, UK) and analysed for external load (represented as Player Load^{TM}: AU) using the following equation (Boyd, Ball, & Aughey, 2011):

$$\text{Playerload} = \frac{\sqrt{(a_{y1}-a_{y-1})^2 + (a_{x1}-a_{x-1})^2 + (a_{z1}-a_{z-1})^2}}{100},$$

where a_y is forward acceleration, a_x is sideways acceleration and a_z is vertical acceleration. This method of quantifying external load has been used widely in team-sports including netball and is a valid and reliable method of measuring team-sports movements (Young et al., 2016). Players wore a heart rate monitor (Team System 2, Polar Electro, Warwick, UK) throughout the session, recorded at beat to beat intervals with data downloaded and analysed using manufacturer's software (Polar Team 2, Polar Electro, Warwick, UK). Mean and maximum HR were calculated from the start of the warm up to the end of the training session.

Ratings of perceived exertion

Players recorded sRPE and dRPE for breathlessness (RPE-B), leg-muscle exertion (RPE-L), upper-body muscle exertion (RPE-U) and cognitive/ technical demands (RPE-T) within 15 minutes of completing netball and strength training. Ratings were provided using a numerically blinded CR100® scale with verbal anchors. Players were familiar with providing sRPE for training sessions and a familiarisation session (performed the week prior to testing) was performed with these scales. Differential ratings of perceived exertion provide a detailed quantification of internal load during team-sport activities (McLaren, Smith, Spears, & Weston, 2017), are sensitive markers of physical exertion (Weston, Siegler, Bahnert, McBrien, & Lovell, 2015) and distinguish between different areas of effort (McLaren et al., 2017; Weston et al., 2015).

Statistical analyses

Visual inspection of the residual plots revealed evidence of heteroscedasticity; therefore, analyses were performed on log-transformed data for all variables apart from HR, BAM+, sRPE and dRPE. Data were analysed via a mixed effects linear model (SPSS v.21, Armonk, NY: IBM Corp.). Fixed effects in the model were order (STR-NET, NET-STR), with players included as a random effect with random intercept to account for the repeated measures nature of the study. Effects (differences between NET-STR and STR-NET) are presented and interpreted as simple effect sizes, either in raw or percent units. Standardised effect sizes (mean difference/pooled standard deviation; SD) are also presented but not interpreted. This was done as simple effect sizes are independent of variance and scaled in the original units of analysis (Baguley, 2009), which maximises the practical context of findings (Pek & Flora, 2018). A clear between-order difference in all dependent variables was declared when the 95% confidence interval for the difference did not include zero.

Results

Training-session order responses for all variables are represented in Table 1. For all variables, comparisons are made to PreS1. Clear differences were observed between trials, with a greater increase following NET-STR for PPO (standardised effect size: 2.8), PPOrel (2.8), JH (2.4) and PV (2.4) at IPS1 compared with STR-NET (Figure 2A). At PreS2, a greater increase was observed following NET-STR for PPOrel (1.4), JH (1.2), PPO (1.2) and PV (1.0) compared with STR-NET. At IPS2, a greater increase was observed following STR-NET for PPO (0.9) and PPOrel (0.8) compared with NET-STR. At 20P, a greater decrease following STR-NET was observed for JH (1.4), PV (1.4), PPOrel (1.2) and PPO (1.1) compared with NET-STR. All other between-order differences were not clear.

*****INSERT TABLE 1 NEAR HERE*****

*****INSERT FIGURE 2A NEAR HERE*****

At IPS1, greater increases following NET-STR were observed for testosterone (1.3) and cortisol concentrations (0.8) compared with STR-NET (Figure 2B). A greater decrease was observed following STR-NET for cortisol concentration (1.0), and a greater increase for T/C ratio (1.1) at PreS2 compared with NET-STR. At IPS2, greater increases in testosterone (1.4), and cortisol (1.0) concentrations were observed following STR-NET compared with NET-STR. All other between-order differences were not clear.

***** INSERT FIGURE 2B NEAR HERE *****

There were no clear differences between trials for soreness, fatigue, motivation or overall mood at any time-point.

Data for the training sessions are represented in Table 2. There were no clear differences between trials for sRPE or dRPE for the netball-training session (Figure 2C). For strength training, a clear difference was observed with a greater RPE-T (1.0) following NET-STR compared with STR-NET. There were no clear differences between trials for external load of netball, maximum HR and average HR.

***** INSERT TABLE 2 NEAR HERE *****

***** INSERT FIGURE 2C NEAR HERE *****

Discussion

This is the first study to examine the influence of training-session order on the acute neuromuscular, endocrine and perceptual responses in International female netball players.

Primary findings highlight that responses both during and after were influenced by the ordering of strength and netball-specific training sessions. Neuromuscular performance and cortisol concentrations were higher prior to commencing the second training session of the day, and neuromuscular performance was higher the following day, in the NET-STR order compared with STR-NET. Accordingly, these data indicate that training-session order is an important consideration when planning training and in order to avoid performing training in a sub-optimal state, technical-netball training should precede strength training.

The performance of NET-STR resulted in an increase in neuromuscular performance (PPO, PPOrel, JH and PV) testosterone and cortisol concentrations at IPS1 compared with that following STR-NET. Following an exercise stimulus, mechanisms of both fatigue and potentiation coexist, with the balance of these factors determining the performance benefit (Kilduff, Finn, Baker, Cook, & West, 2013). It is therefore possible that the greater increase in testosterone concentrations following netball training, perhaps resulting from an increase in competitive and dominance behaviours from playing against peers (Edwards & Kurlander, 2010), may have positively influenced behaviour, contractile signalling and performance (Crewther, Cook, Cardinale, Weatherby, & Lowe, 2011). This in turn may have had a positive impact on neuromuscular function, to a greater extent than acute impairment by either muscle damage or fatigue, compared with responses to strength training. Additionally, muscle temperature may have increased to a greater degree following netball training, along with induction of post-activation potentiation due to dynamic movements (Turner, Bellhouse, Kilduff, & Russell, 2015), greater than achieved following strength training.

Prior to commencing the second training session of the day (PreS2), neuromuscular performance was enhanced, and cortisol concentration increased in the NET-STR versus STR-NET trial. Multiple mechanisms may have contributed to the differences in neuromuscular performance observed. Cortisol has been proposed to work in tandem with testosterone to impact neuromuscular performance (Crewther, Obmiński, & Cook, 2018), and may have exerted a positive impact in the present study. The greater volume, intensity or type of exercise performed in netball training could have also led to greater increases in core (Mcgowan et al., 2017) and muscle temperature than that of strength training, resulting in improved neuromuscular function (West et al., 2014). Moreover, repeated high intensity concentric and eccentric contractions involved in strength training could have led to a greater impairment of excitation-contraction coupling compared to netball training, resulting from low-frequency fatigue (McLellan & Lovell, 2012), with exercise-induced muscle damage and damage to type two muscle fibres (Byrne, Twist, & Eston, 2004) contributing to the decrease. Performing subsequent training with impaired neuromuscular performance can impair subsequent training performance (Highton, Twist, & Eston, 2009) and adaptation to training (Jones et al., 2016). Findings therefore suggest that to avoid compromising subsequent training performance, netball training should be performed prior to strength training.

No differences were observed between trials for external or internal intensity of the netball-training session. Despite reduced neuromuscular performance, prior strength training had no impact upon playing intensity of netball, similar to previously reported in football (Sparkes et al., 2020). Whilst players may have compensated to maintain the required intensity, playing intensity was maintained without any change to heart rate or perceived effort, suggesting that the prior strength training had no effect on subsequent netball-training performance. It should be noted however, that the aims of the netball-training session were technical in nature, and therefore the impact of prior exercise on more maximal type exercise is unclear and warrants further investigation. Perceived technical/cognitive demands of the strength-training session were increased when preceded by netball. Whilst this does not indicate players were overly exerted, coaches and conditioning coaches should be aware of this when planning training and modify technically challenging exercises based on individual player's needs.

When players reported for training at 20P, neuromuscular performance was reduced following STR-NET compared with NET-STR, whilst markers of endocrine function and mood were similar. Following speed and strength training (Johnston et al., 2017), and small-sided games and strength training (Sparkes et al., 2020), training-session order had no impact on neuromuscular performance the following day in elite male players. However, endurance running performance was impaired when strength training preceded running training relative to the opposite order (Doma & Deakin, 2013). A difference between these findings may be due to recovery of neuromuscular performance before commencement of subsequent training, whereby greater fatigue was experienced when training was performed without recovery of neuromuscular performance (Doma & Deakin, 2013). The present study supports these findings and suggests that recovery of neuromuscular performance prior to the performance of subsequent training may influence the associated recovery profile. Importantly, no differences were observed between trials at 20P (or at PreS2) for any perceptual marker of fatigue, despite reduced neuromuscular performance. This highlights the importance of utilising objective, in addition to subjective, markers of fatigue and readiness to train, to understand responses to, and recovery from, training.

We acknowledge limitations in this study design. There was no control in place for menstrual cycle phase, or hormonal contraceptive use. However a recent meta-analysis (McNulty et al., 2020) reported a trivial effect of menstrual cycle phase on exercise performance, whilst a previous report in elite female athletes suggest similar patterns in hormonal responses to training and competition with and without hormonal contraceptive use (Crewther, Hamilton, Casto, Kilduff, & Cook, 2015). We also could not randomise training order due to the training commitments of elite players, and numbers of players required for training sessions. We compared players responses to their daily baseline value, rather than between trials, to eliminate circadian rhythm and menstrual cycle influences, players were prescribed the same training in the days before testing across both trials, and all players were familiarised with both session orders. Additionally, whilst players were provided nutritional advice with regards to how to optimally prepare for and recover from training, there were no controls in place to ensure this, particularly on the days prior to testing when players were not performing training as a squad. These are, however, inherent limitations when conducting research in elite athletes.

Conclusion

This is the first study to report the influence of sequencing of strength and netball training within a day on the acute neuromuscular, endocrine and perceptual responses in International female netball players. Sequencing of training impacted neuromuscular performance and endocrine function within the training day, and neuromuscular performance the following day, without impact upon training performance. Findings suggest that in order to avoid performing training in a sub-optimal state, technical netball training should precede strength training.

References

Baguley, T. (2009). Standardized or simple effect size: What should be reported? *British Journal of Psychology*, *100*(3), 603–617. https://doi.org/10.1348/000712608X377117

Bailey, J. A., Gastin, P. B., Mackey, L., & Dwyer, D. B. (2017). The Player Load Associated With Typical Activities in Elite Netball. *International Journal of Sport Physiology and Performance*, *12*, 1218–1223. https://doi.org/https://doi.org/10/1123/ijspp.2016.0378

Barrett, S., Midgley, A., & Lovell, R. (2014). PlayerLoad™: Reliability, convergent validity, and influence of unit position during treadmill running. *International Journal of Sports Physiology and Performance*, *9*(6), 945–952. https://doi.org/10.1123/ijspp.2013-0418

Birdsey, L. P., Weston, M., Russell, M., Johnston, M. J., Cook, C. J., & Kilduff, L. P. (2019). Neuromuscular, physiological and perceptual responses to an elite netball tournament. *Journal of Sports Sciences*, *00*(00), 1–6. https://doi.org/10.1080/02640414.2019.1625613

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The relaibility of MinimaxX accelerometers for measuring physical activity in Australian football. *International Journal of Sport Physiology and Performance*, *6*, 311–321. https://doi.org/10.1123/ijspp.6.3.311

Brownstein, C. G., Dent, J. P., Parker, P., Hicks, K. M., Howatson, G., Goodall, S., & Thomas, K. (2017). Etiology and recovery of neuromuscular fatigue following competitive soccer match-play. *Frontiers in Physiology*, *8*(OCT). https://doi.org/10.3389/fphys.2017.00831

Byrne, C., Twist, C., & Eston, R. (2004). Neuromuscular function after exercise-induced muscle damage: theoretical and applied implications. *Sports Medicine (Auckland, N.Z.)*, *34*(1), 49–69. https://doi.org/https://doi.org/0112-1642/04/0001-0049/$31.00/0

Chandler, P., Pinder, S., Curran, J., & Gabb. (2014). Physical demands of training and competition in collegiate netball players. *Journal of Strength and Conditioning Research*, *28*(10), 2732–2737. https://doi.org/10.1519/1533-4287(2005)19<202

Crewther, B. T., Cook, C. J., Cardinale, M., Weatherby, R., & Lowe, T. (2011). Two emerging concepts for elite athletes. *Sports Medicine*, *41*(2), 103–123. https://doi.org/10.2165/11536850-000000000-00000

Crewther, B. T., Hamilton, D., Casto, K., Kilduff, L. P., & Cook, C. J. (2015). Effects of oral contraceptive use on the salivary testosterone and cortisol responses to training sessions and competitions in elite women athletes. *Physiology and Behavior*, *147*, 84–90. https://doi.org/10.1016/j.physbeh.2015.04.017

Crewther, B. T., Obmiński, Z., & Cook, C. J. (2018). Serum cortisol as a moderator of the relationship between serum testosterone and Olympic weightlifting performance in real and simulated competitions. *Biology of Sport*, *35*(3), 215–221. https://doi.org/10.5114/biolsport.2018.74632

Crewther, B. T., Sanctuary, C. E., Kilduff, L. P., Carruthers, J. S., Gaviglio, C. M., & Cook, C. J. (2013). The Workout Responses of Salivary-Free Testosterone and Cortisol Concentrations and Their Association With the Subsequent Competition Outcomes in Professional Rugby League. *Journal of Strength and Conditioning Research*, *27*(2), 471–476. https://doi.org/10.1519/JSC.0b013e3182577010

Doma, K., & Deakin, G. B. (2013). The effects of strength training and endurance training order on running economy and performance. *Applied Physiology, Nutrition and Metabolism*, *656*(January), 651–656. https://doi.org/10.1139/apnm-2012-0362

Edwards, D. A., & Kurlander, L. S. (2010). Women's intercollegiate volleyball and tennis: Effects of warm-up, competition, and practice on saliva levels of cortisol and testosterone. *Hormones and Behavior*, *58*(4), 606–613. https://doi.org/10.1016/j.yhbeh.2010.06.015

Fox, A., Spittle, M., Otago, L., & Saunders, N. (2013). Activity profiles of the Australian female netball team players during international competition: implications for training practice. *Journal of Sports Sciences*, *31*(14), 1588–1595. https://doi.org/10.1080/02640414.2013.792943

García-Pallarés, J., Sánchez-Medina, L., Carrasco, L., Díaz, A., & Izquierdo, M. (2009). Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle. *European Journal of Applied Physiology*, *106*(4), 629–638. https://doi.org/10.1007/s00421-009-1061-2

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. *International Journal of Sports Physiology and Performance*, *10*(1), 84–92. https://doi.org/10.1123/ijspp.2013-0413

Hawley, J. A. (2009). Molecular responses to strength and endurance training: Are they incompatible? *Applied Physiology, Nutrition and Metabolism*, *34*(3), 355–361. https://doi.org/10.1139/H09-023

Highton, J. M., Twist, C., & Eston, R. G. (2009). The effects of exercise-induced muscle damage on agility and sprint running performance. *Journal of Exercise Science and Fitness*, *7*(1), 24–30. https://doi.org/10.1016/S1728-869X(09)60004-6

Johnston, M. J., Johnston, J., Cook, C. J., Costley, L., Kilgallon, M., & Kilduff, L. P. (2017). The effect of session order on the physiological, neuromuscular, and endocrine responses to maximal speed and weight training sessions over a 24-h period. *Journal of Science and Medicine in Sport*, *20*(5), 502–506.

https://doi.org/10.1016/j.jsams.2016.03.007

Jones, T. W., Howatson, G., Russell, M., & French, D. (2016). Performance and endocrine responses to differing ratios of concurrent strength and endurance training. *Journal of Strength and Conditioning Research*, *30*(3), 693–702.

Kilduff, L. P., Finn, C. V., Baker, J. S., Cook, C. J., & West, D. J. (2013). Preconditioning strategies to enhance physical performance on the day of competition. *International Journal of Sports Physiology and Performance*, *8*(6), 677–681. https://doi.org/10.1123/ijspp.8.6.677

Lepers, R., Maffiuletti, N. A., Rochette, L., Brugniaux, J., & Millet, G. Y. (2002). Neuromuscular fatigue during a long-duration cycling exercise. *Journal of Applied Physiology*, *92*(4), 1487–1493. https://doi.org/10.1152/japplphysiol.00880.2001

Leveritt, M., Abernethy, P. J., Barry, B. K., & Logan, P. A. (1999). Concurrent strength and endurance training. A review. *Sports Medicine*, *28*(6), 413–427. https://doi.org/10.2165/00007256-199928060-00004

Mcgowan, C. J., Pyne, D. B., Thompson, K. G., Raglin, J. S., & Rattray, B. (2017). Morning Exercise : Enhancement of Afternoon Sprint-Swimming Performance. *International Journal of Sports Physiology and Performance*, *12*, 605–611.

McLaren, S. J., Smith, A., Spears, I. R., & Weston, M. (2017). A detailed quantification of differential ratings of perceived exertion during team-sport training. *Journal of Science and Medicine in Sport*, *20*(3), 290–295. https://doi.org/10.1016/j.jsams.2016.06.011

McLellan, C. P., & Lovell, D. I. (2012). Neuromuscular responses to impact and collision during elite rugby league match play. *Journal of Strength and Conditioning Research*, *26*(5), 1431–1440.

McNulty, K. L., Elliott-Sale, K. J., Dolan, E., Swinton, P. A., Ansdell, P., Goodall, S., … Hicks, K. M. (2020). The Effects of Menstrual Cycle Phase on Exercise Performance in Eumenorrheic Women: A Systematic Review and Meta-Analysis. *Sports Medicine*, (0123456789). https://doi.org/10.1007/s40279-020-01319-3

Owen, N., Watkins, J., Kilduff, L. P., Bevan, H., & Bennett, M. (2014). Development of a Criterion Method to Determine Peak Mechanical Power Output in a Countermovement Jump. *Journal of Strength and Conditioning Research*, *28*(6), 1552–1558.

Pek, J., & Flora, D. B. (2018). Reporting effect sizes in original psychological research: A discussion and tutorial. *Psychological Methods*, *23*(2), 208–225. https://doi.org/10.1037/met0000126

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2011). Effect of post-match cold-water immersion on subsequent match running performance in junior soccer players during tournament play. *Journal of Sports Sciences*, *29*(1), 1–6. https://doi.org/10.1080/02640414.2010.512640

Russell, M., King, A., Bracken, R. M., Cook, C. J., Giroud, T., & Kilduff, L. P. (2016). A Comparison of Different Modes of Morning Priming Exercise on Afternoon Performance. *International Journal of Sport Physiology and Performance*, *11*(6), 763–767.

Seiler, S., Haugen, O., & Kuffel, E. (2007). Autonomic Recovery after Exercise in Trained Athletes: Intensity and Duration Effects. *Medicine and Science in Sports and Exercise*, *39*(8), 1366–1373. https://doi.org/10.1249/mss.0b013e318060f17d

Shearer, D. A., Sparkes, W., Northeast, J., Cunningham, D. J., Cook, C. J., & Kilduff, L. P. (2017). Measuring recovery: An adapted Brief Assessment of Mood (BAM+) compared to biochemical and power output alterations. *Journal of Science and Medicine in Sport*, *20*(5), 512–517. https://doi.org/10.1016/j.jsams.2016.09.012

Simpson, M. J., Jenkins, D. G., Scanlan, A. T., & Kelly, V. G. (2020). Relationships Between External- and Internal-Workload Variables in an Elite Female Netball Team and Between Playing Positions. *International Journal of Sports Physiology and Performance*, *15*(6), 841–846. https://doi.org/10.1123/ijspp.2019-0619

Sparkes, W., Turner, A. N., Weston, M., Russell, M., Johnston, M. J., & Kilduff, L. P. (2020). The effect of training order on neuromuscular, endocrine and mood response to small-sided games and resistance training sessions over a 24-h period. *Journal of Science and Medicine in Sport*, *23*(9), 866–871. https://doi.org/10.1016/j.jsams.2020.01.017

Turner, A. P., Bellhouse, S., Kilduff, L. P., & Russell, M. (2015). Postactivation Potentiation of Sprint Acceleration Performance Using Plyometric Exercise. *Journal of Strength and Conditioning Research*, *29*(2), 343–350.

West, D. J., Cook, C. J., Beaven, M., & Kilduff, L. P. (2014). The Influence of the Time of Day on Core Temperature and Lower Body Power Output in Elite Rugby Union Sevens Players. *Journal of Strength and Conditioning Research*, *28*(6), 1524–1528. https://doi.org/10.1519/R-21636.1

Weston, M., Siegler, J., Bahnert, A., McBrien, J., & Lovell, R. (2015). The application of differential ratings of perceived exertion to Australian Football League matches. *Journal of Science and Medicine in Sport*, *18*(6), 704–708. https://doi.org/10.1016/j.jsams.2014.09.001

Young, C. M., Gastin, P. B., Sanders, N., Mackey, L., & Dwyer, D. B. (2016). Player load in elite netball: Match, training, and positional comparisons. *International Journal of Sports Physiology and Performance*, *11*(8), 1074–1079.

https://doi.org/10.1123/ijspp.2015-0156

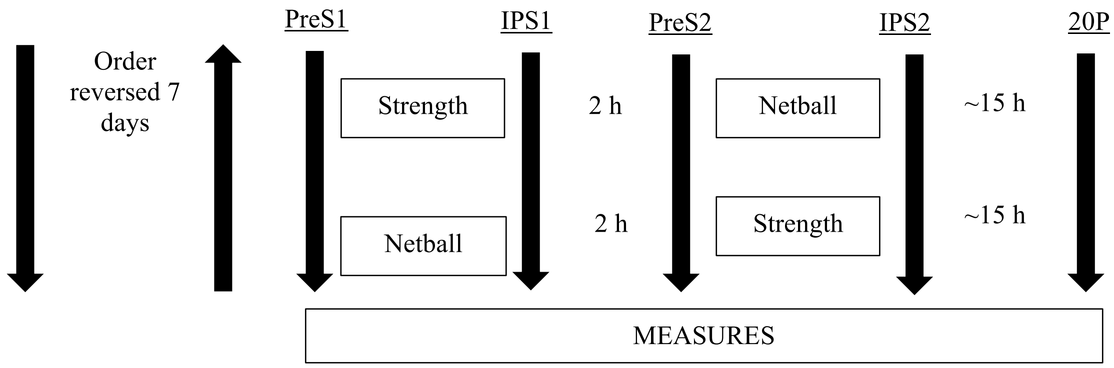

Figure 1: Schematic outlining the design of the study. Measures (salivary cortisol and testosterone concentrations, countermovement jump testing, perceived mood) were performed within 15 minutes of commencing session one (PreS1), within 15 minutes post session one (IPS1), two hours post session one/ within 15 minutes of commencing session two (PreS2), within 15 minutes post session two (IPS2) and 20 h post session one (20P). This was repeated for both session orders, with strength followed by netball training (STR-NET) and netball followed by strength training (NET-STR) separated by seven days.

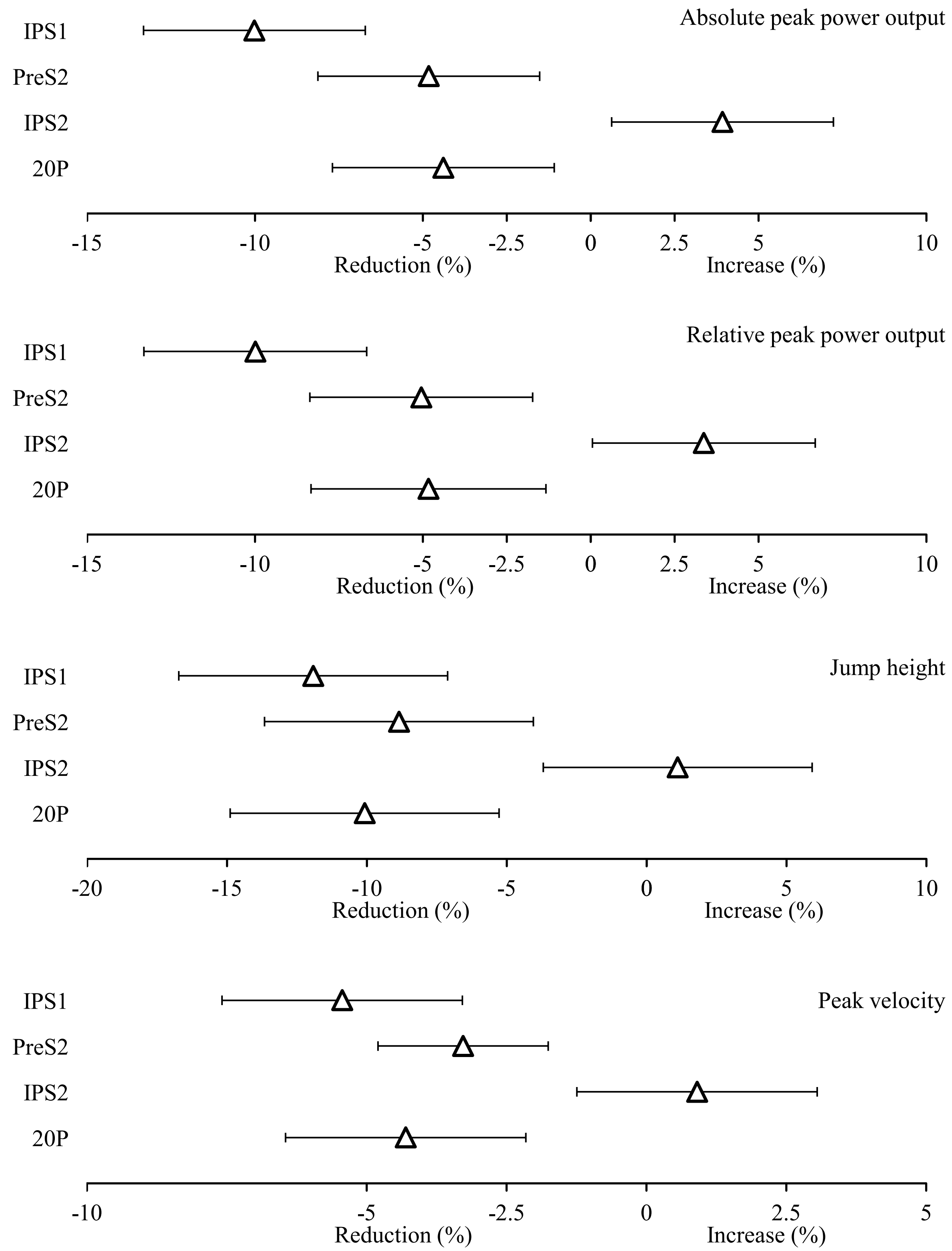

Figure 2A: Effect statistics (mean difference in percent and 95% confidence intervals) for the comparison of absolute peak power output, peak power output relative to mass, jump height and peak velocity at immediately post session one (IPS1), pre session two (PreS2), immediately post session two (IPS2) and 20 hours post session one (20P) compared to baseline for STR-NET compared with NET-STR. Zero (0) on the axis represents no difference between trials at that time-point compared with baseline.

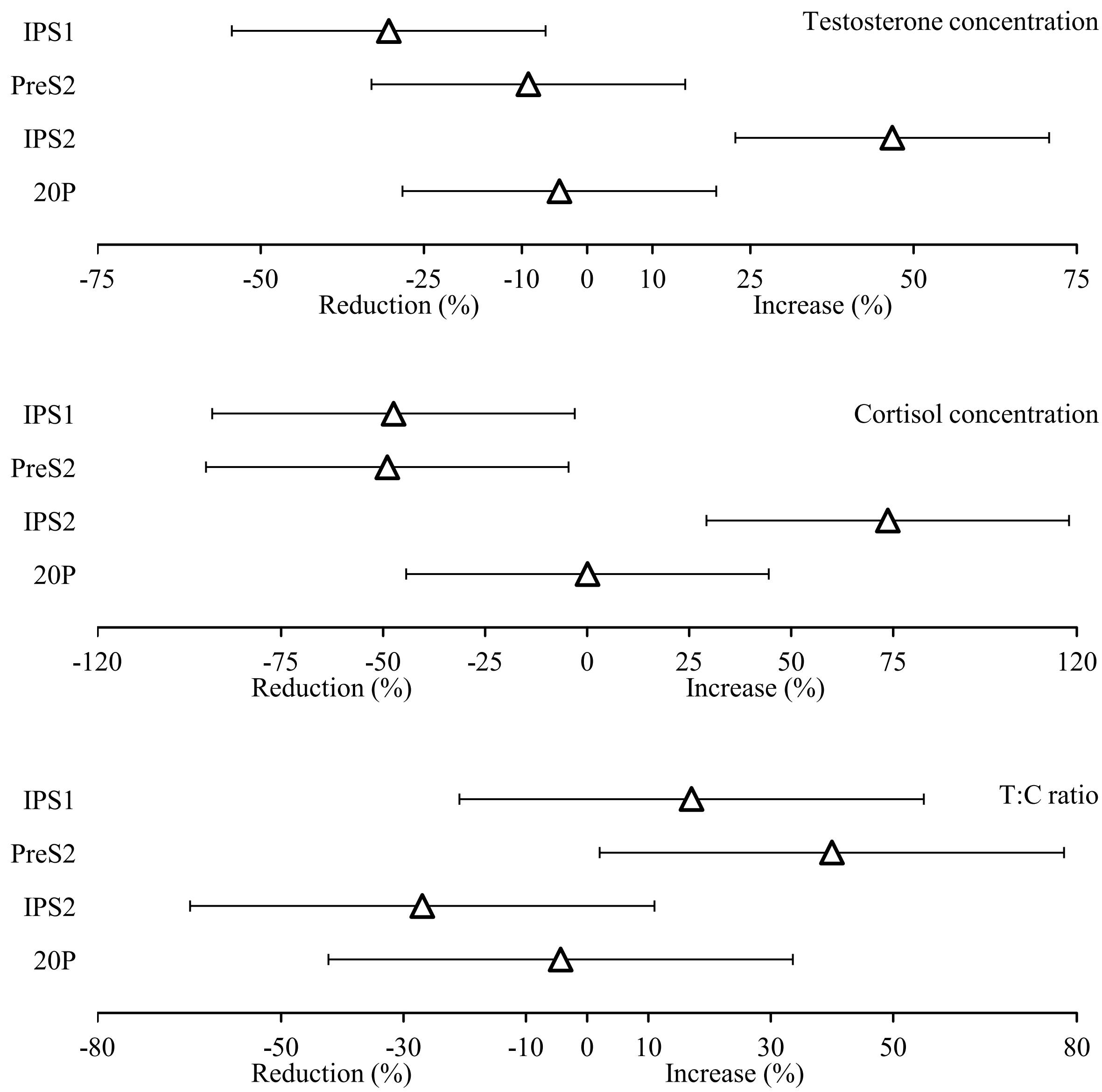

Figure 2B: Effect statistics (mean difference in percent and 95% confidence intervals) for the comparison of testosterone concentration, cortisol concentration and testosterone to cortisol ratio at immediately post session one (IPS1), pre session two (PreS2), immediately post session two (IPS2) and 20 hours post session one (20P) compared to baseline for STR-NET compared with NET-STR. Zero (0) on the axis represents no difference between trials at that time-point compared with baseline.

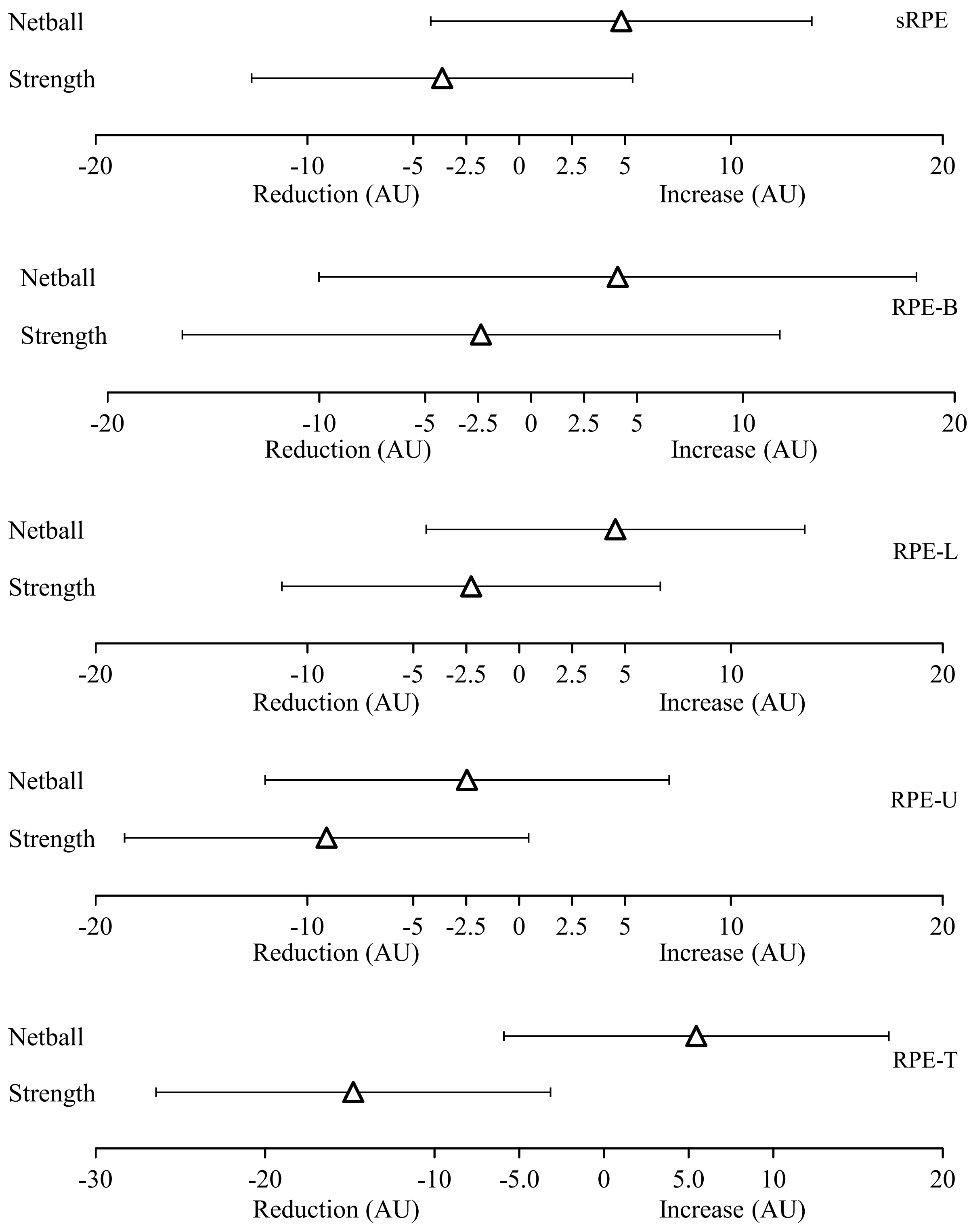

Figure 2C: Effect statistics (mean difference in arbitrary units [AU] and 95% confidence intervals) for the comparison of STR-NET compared with NET-STR for session rating of perceived exertion (sRPE), rating of perceived breathlessness (RPE-B), leg-muscle exertion (RPE-L), upper-body exertion (RPE-U) and cognitive/ technical demand (RPE-T) at immediately post session one (IPS1), pre session two (PreS2), immediately post session two (IPS2) and 20 hours post session one (20P) compared to baseline for STR-NET compared with NET-STR. Zero (0) on the axis represents no difference between trials at that time-point compared with baseline.

Table 1: Mean (± SD) of endocrine function (T, C, T:C), countermovement jump variables (PPOabs, PPOrel, JH, PV) and well-being (mood, fatigue, soreness, motivation) for SRT-NET and NET-STR at each time-point.

	PreS1	IPS1	PreS2	IPS2	20P
STR-NET					
T (pg·ml^{-1})	82.5 ± 34.5	91.2 ± 25.8	69.7 ± 20.7	117.3 ± 44.3	85.3 ± 29.1
C (µg·dl^{-1})	0.18 ± 0.07	0.18 ± 0.11	0.11 ± 0.04	0.34 ± 0.33	0.75 ± 0.52
T:C	489 ± 215	665 ± 332	686 ± 308	550 ± 389	148 ± 79
PPOabs (W)	3895 ± 538	3812 ± 611	3793 ± 519	3996 ± 610	3715 ± 536
PPOrel (W·kg^{-1})	50.9 ± 4.8	49.7 ± 5.6	49.4 ± 5.3	51.9 ± 5.8	48.2 ± 4.5
JH (m)	0.32 ± 0.04	0.30 ± 0.04	0.29 ± 0.03	0.31 ± 0.04	0.29 ± 0.04
PV (m·s^{-1})	2.61 ± 0.13	2.53 ± 0.12	2.54 ± 0.13	2.60 ± 0.14	2.49 ± 0.14
Mood (AU)	35 ± 28	-	-	-	12 ± 28
Fatigue (AU)	38 ± 25	47 ± 15	48 ± 13	61 ± 14	61 ± 22
Soreness (AU)	36 ± 28	56 ± 18	58 ± 18	57 ± 17	62 ± 16
Motivation (AU)	63 ± 16	65 ± 15	56 ± 18	56 ± 18	49 ± 20
NET-STR					
T (pg·ml^{-1})	69.2 ± 16.5	108.7 ± 28.8	67.2 ± 20.5	67.5 ± 29.4	75.4 ± 20.1
C (µg·dl^{-1})	0.16 ± 0.08	0.21 ± 0.12	0.15 ± 0.07	0.11 ± 0.04	0.57 ± 0.20
T:C	532 ± 261	577 ± 238	532 ± 261	643 ± 220	147 ± 57
PPOabs (W)	3879 ± 516	4171 ± 410	3966 ± 543	3819 ± 501	3857 ± 466
PPOrel (W·kg^{-1})	50.4 ± 4.8	54.3 ± 4.9	51.5 ± 5.4	49.7 ± 4.7	50.1 ± 4.9
JH (m)	0.30 ± 0.05	0.32 ± 0.03	0.31 ± 0.03	0.29 ± 0.03	0.30 ± 0.03
PV (m·s^{-1})	2.57 ± 0.17	2.63 ± 0.12	2.57 ± 0.17	2.53 ± 0.12	2.55 ± 0.11
Mood (AU)	26 ± 29	-	-	-	9 ± 19
Fatigue (AU)	39 ± 21	55 ± 16	50 ± 20	58 ± 11	56 ± 14
Soreness (AU)	29 ± 18	44 ± 22	51 ± 19	60 ± 14	51 ± 11
Motivation (AU)	58 ± 19	54 ± 16	51 ± 14	45 ± 16	52 ± 13

Abbreviations: SD: standard deviation; T: testosterone concentration; C: cortisol concentration; T:C: testosterone to cortisol ratio; PPOabs: absolute peak power output; PPOrel: peak power output relative to mass; JH: jump height; PV: peak velocity; Mood: overall mood score from brief assessment of mood +; Fatigue: perceived fatigue; Soreness: perceived muscle soreness; Motivation: perceived motivation.

Table 2: Mean (± SD) of internal (mean HR, maximum HR) and external intensity of the netball-training session, and perception of effort (sRPE, RPE-B, RPE-L, RPE-U, RPE-T) for the netball and strength-training sessions for both STR-NET and NET-STR.

	Netball training		Strength training	
	STR-NET	NET-STR	STR-NET	NET-STR
Mean HR ($b \cdot min^{-1}$)	147 ± 8	143 ± 13	-	-
Maximum HR ($b \cdot min^{-1}$)	197 ± 3	197 ± 3	-	-
External intensity ($AU \cdot min^{-1}$)	4.1 ± 0.4	4.1 ± 0.5	-	-
sRPE (AU)	58 ± 9	53 ± 14	47 ± 11	51 ± 12
RPE-B (AU)	48 ± 12	44 ± 21	29 ± 20	31 ± 14
RPE-L (AU)	49 ± 15	45 ± 15	56 ± 10	59 ± 8
RPE-U (AU)	29 ± 11	31 ± 13	40 ± 15	49 ± 10
RPE-T (AU)	52 ± 11	46 ± 13	25 ± 9	40 ± 18

Abbreviations: SD: standard deviation; STR-NET: strength followed by netball session order; NET-STR: netball followed by strength session order; HR: heart rate; sRPE: session rating of perceived exertion; RPE-B: perceived breathlessness; RPE-L: perceived leg-muscle exertion; RPE-U: perceived upper-body muscle exertion; RPE-T: perceived cognitive/ technical demand.