

Please cite the Published Version

Birdsey, Laurence P, Weston, Matthew, Russell, Mark, Johnston, Michael, Cook, Christian J and Kilduff, Liam P (2022) The neuromuscular, physiological, endocrine and perceptual responses to different training session orders in international female netball players. *European Journal of Sport Science*, 22 (3). pp. 314-325. ISSN 1536-7290

DOI: <https://doi.org/10.1080/17461391.2020.1869837>

Publisher: Taylor & Francis

Version: Accepted Version

Downloaded from: <https://e-space.mmu.ac.uk/630416/>

Usage rights:  [Creative Commons: Attribution-Noncommercial 4.0](https://creativecommons.org/licenses/by-nc/4.0/)

Additional Information: This is an Author Accepted Manuscript of an article published in *European Journal of Sport Science*, by Taylor & Francis.

Enquiries:

If you have questions about this document, contact openresearch@mmu.ac.uk. Please include the URL of the record in e-space. If you believe that your, or a third party's rights have been compromised through this document please see our Take Down policy (available from <https://www.mmu.ac.uk/library/using-the-library/policies-and-guidelines>)

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

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22 Word count: 3998

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

25

26 The 20 h responses of International female netball players to training days requiring two
27 sessions (netball and strength, separated by two hours) ordered alternatively were examined.
28 Eleven players completed strength followed by netball training two hours later (STR-NET),
29 with the order reversed (NET-STR) on a separate day. Well-being, neuromuscular performance
30 (jump height [JH], peak power output [PPO], peak velocity [PV]) and endocrine function
31 (testosterone, cortisol concentrations) were measured before sessions one (PreS1) and two
32 (PreS2), immediately after sessions one (IPS1) and two (IPS2), and 20 h post session one (20P).
33 Session and differential ratings of perceived exertion (upper-body, cognitive/technical [RPE-
34 T], lower-body, breathlessness), were collected, and accelerometry and heart rate measured
35 netball load. Identification of clear between-order differences were based on the nonoverlap of
36 the 95% confidence interval (95%CI) for mean differences relative to baseline. Compared to
37 PreS1, greater increases in JH (percentage difference between trials; 95%CI: 9%; 4 to 14%),
38 PPO (5%; 2 to 8%), PV (3%; 1 to 5%) and cortisol concentration (45%; 1 to 88%), and a greater
39 decrease for testosterone/cortisol ratio (-35%; -72 to -2%) occurred at PreS2 in NET-STR. At
40 20P, greater decreases in JH (10%; 5 to 15%), PPO (4%; 1 to 8%) and PV (4%; 2 to 6%) were
41 observed following STR-NET. No differences existed for well-being, whilst RPE-T was
42 greater (15 AU; 3 to 26 AU) for strength training during NET-STR. Session order influenced
43 neuromuscular and endocrine responses in International female netball players, highlighting
44 session ordering as a key consideration when planning training.

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

46

47 **Introduction**

48 Netball in an intermittent team-sport with court movement restrictions yielding unique
49 position-specific movement and playing demands (Young, Gastin, Sanders, Mackey, & Dwyer,
50 2016). This results in an intense, intermittent activity profile involving short explosive
51 movements, interspersed with short recovery periods (Fox, Spittle, Otago, & Saunders, 2013).
52 Mid-court positions perform at higher internal and external intensities than goal-based
53 positions (Birdsey et al., 2019), whilst each position performs a unique set of locomotor and
54 non-locomotor activities which contribute to the total load (Bailey, Gastin, Mackey, & Dwyer,
55 2017). In order to prepare for these demands, players often perform multiple training sessions
56 within a day (Simpson, Jenkins, Scanlan, & Kelly, 2020). This includes technical on-court
57 training, on and off-court conditioning, in addition to strength training (Chandler, Pinder,
58 Curran, & Gabb, 2014; Simpson et al., 2020) in order to develop physical, technical and tactical
59 aspects of match-play. As players perform training to improve unique aspects related to netball
60 performance (Young et al., 2016) the applicability of findings from other team-sports may be
61 limited. It is therefore imperative that responses to netball-specific training are fully
62 understood, however, this is currently lacking.

63

64 To overload specific variables that optimise physical performance preparation, professional
65 team-sport athletes often perform multiple training sessions per day (Johnston et al., 2017),
66 including technical, speed, aerobic and strength-focused activities. Whilst some studies report
67 positive adaptations to the performance of multiple training sessions, or training aims, in a
68 concurrent training paradigm (García-Pallarés, Sánchez-Medina, Carrasco, Díaz, & Izquierdo,
69 2009), a reduced training effect (Jones, Howatson, Russell, & French, 2016), proposed due to
70 a failure to maintain training performance (Leveritt, Abernethy, Barry, & Logan, 1999) and
71 compromised molecular signalling (Hawley, 2009), may also occur. The physiological

72 responses to, and fatigue experienced after, exercise is specific to the intensity (Seiler, Haugen,
73 & Kuffel, 2007), volume (Lepers, Maffiuletti, Rochette, Brugniaux, & Millet, 2002) and mode
74 (Sparkes et al., 2020) and can persist for several days (Brownstein et al., 2017). Therefore, the
75 ordering of training sessions within a concurrent training paradigm is important when
76 determining subsequent training performance (Johnston et al., 2017) and ensuing adaptations
77 (Jones et al., 2016).

78

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

94

95 Netball has unique movement and playing demands, and as physiological responses are
96 influenced by many factors (Lepers et al., 2002; Seiler et al., 2007; Sparkes et al., 2020), it is

97 vital that responses to netball-specific training are fully understood. In preparing for the
98 demands of International netball, it is commonplace to perform multiple within-day training
99 sessions, however limited literature has identified if session order affects responses both during
100 and after training sessions; data which has implications for programming. An understanding of
101 the acute post-training fatigue and recovery responses to session order can allow the coach to
102 effectively plan training to optimise adaptation. Therefore, the purpose of this study was to
103 compare the physiological, endocrine and perceptual responses to a training day consisting of
104 both strength and netball-training sessions performed two hours apart, executed as both
105 strength training followed by netball training and netball training followed by strength training.

106

107 **Material and Methods**

108 *Participants*

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

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

126

127 *Design*

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

136

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

138

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

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

160

161 *Netball-training session*

162 The on-court netball-training session had a duration of 107 min (\pm 2.8 min). This was a
163 routinely performed session by the team, which had featured regularly in the pre-season period,
164 with the aim of developing technical skills, movement patterns and decision making. Initially,
165 players performed a court-based warm-up of 19.7 min (\pm 0.9 min), consisting of team-based
166 exercises involving changes of direction, short sprints, dynamic stretching, ball skills and
167 netball specific movements. Four technical drills were then performed, focussed around
168 creating and using options. This progressed from one on one in a small square (approximately
169 three by three metres) to two on two in a larger space (approximately four by four metres)
170 aiming to create space to both make and receive a pass from a feeder outside the square. Next,
171 this was performed in the goal circle, with the aiming of scoring, with the final drill involving

172 two attackers taking the ball past two defenders in each third, before passing the ball to a goal
173 shooter. For both the STR-NET and NET-STR trials, the same session was performed.

174

175 *Strength-training session*

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

182

183 *Mood*

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

193

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

196

197 This method of calculating mood has acceptable internal consistency (cronbach alpha score of
198 0.65 to 0.82; Shearer et al., 2017) and is moderately correlated to high intensity match activity
199 (Shearer et al., 2017). Additionally, it is sensitive to physiological responses following
200 competition (Shearer et al., 2017) and training (Sparkes et al., 2020) in elite team-sport players,
201 and following netball match-play (Birdsey et al., 2019). Individual scores for perceived muscle
202 soreness, fatigue and motivation were also assessed, as these markers are sensitive to netball
203 match-play (Birdsey et al., 2019), to soccer training (Brownstein et al., 2017) and may impact
204 athletic performance (Rowell, Coutts, Reaburn, & Hill-Haas, 2011).

205

206 *Endocrine function*

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

216

217 *Neuromuscular performance*

218 To measure ground reaction force time history of countermovement jumps a portable force
219 platform with built-in charge amplifier (type 92866AA, Kistler Instruments Ltd., Farnborough,
220 UK) was used with a sample rate of 1000 Hz, and calibration confirmed pre-testing. Jump
221 height calculated from take-off velocity (CV=3.4%) and power (CV=2.4%) were calculated

222 using previously established procedures (Owen, Watkins, Kilduff, Bevan, & Bennett, 2014),
223 along with PV which has low variability (CV=2.5%; Gathercole, Sporer, Stellingwerff, &
224 Sleivert, 2015). Prior to countermovement jump testing players performed a standardised
225 warm-up (two sets of 10 repetitions of the lunge, side lunge and squat exercises, followed by
226 two practice countermovement jumps), apart from immediately post-training (IPS1, IPS2), at
227 which point one practice jump was performed only. Countermovement jump testing was
228 performed within 15 minutes of commencing and within five minutes of completing each
229 training session. Players performed two jumps, with the best jump used in subsequent analyses,
230 were instructed to jump as high and as fast as possible, to keep hands on hips throughout the
231 jump, and were familiar with this testing procedure.

232

233 *Exercise intensity*

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

243

$$244 \text{ Playerload} = \frac{\sqrt{(a_{y1}-a_{y-1})^2 + (a_{x1}-a_{x-1})^2 + (a_{z1}-a_{z-1})^2}}{100}$$

245

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

253

254 *Ratings of perceived exertion*

255 Players recorded sRPE and dRPE for breathlessness (RPE-B), leg-muscle exertion (RPE-L),
256 upper-body muscle exertion (RPE-U) and cognitive/ technical demands (RPE-T) within 15
257 minutes of completing netball and strength training. Ratings were provided using a numerically
258 blinded CR100® scale with verbal anchors. Players were familiar with providing sRPE for
259 training sessions and a familiarisation session (performed the week prior to testing) was
260 performed with these scales. Differential ratings of perceived exertion provide a detailed
261 quantification of internal load during team-sport activities (McLaren, Smith, Spears, & Weston,
262 2017), are sensitive markers of physical exertion (Weston, Siegler, Bahnert, McBrien, &
263 Lovell, 2015) and distinguish between different areas of effort (McLaren et al., 2017; Weston
264 et al., 2015).

265

266 *Statistical analyses*

267 Visual inspection of the residual plots revealed evidence of heteroscedasticity; therefore,
268 analyses were performed on log-transformed data for all variables apart from HR, BAM+,
269 sRPE and dRPE. Data were analysed via a mixed effects linear model (SPSS v.21, Armonk,
270 NY: IBM Corp.). Fixed effects in the model were order (STR-NET, NET-STR), with players

271 included as a random effect with random intercept to account for the repeated measures nature
272 of the study. Effects (differences between NET-STR and STR-NET) are presented and
273 interpreted as simple effect sizes, either in raw or percent units. Standardised effect sizes (mean
274 difference/pooled standard deviation; SD) are also presented but not interpreted. This was done
275 as simple effect sizes are independent of variance and scaled in the original units of analysis
276 (Baguley, 2009), which maximises the practical context of findings (Pek & Flora, 2018). A
277 clear between-order difference in all dependent variables was declared when the 95%
278 confidence interval for the difference did not include zero.

279

280 **Results**

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

290

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

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

293

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

300

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

302

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

305

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

311

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

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

314

315 **Discussion**

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

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

325

326 The performance of NET-STR resulted in an increase in neuromuscular performance (PPO,
327 PPOrel, JH and PV) testosterone and cortisol concentrations at IPS1 compared with that
328 following STR-NET. Following an exercise stimulus, mechanisms of both fatigue and
329 potentiation coexist, with the balance of these factors determining the performance benefit
330 (Kilduff, Finn, Baker, Cook, & West, 2013). It is therefore possible that the greater increase in
331 testosterone concentrations following netball training, perhaps resulting from an increase in
332 competitive and dominance behaviours from playing against peers (Edwards & Kurlander,
333 2010), may have positively influenced behaviour, contractile signalling and performance
334 (Crewther, Cook, Cardinale, Weatherby, & Lowe, 2011). This in turn may have had a positive
335 impact on neuromuscular function, to a greater extent than acute impairment by either muscle
336 damage or fatigue, compared with responses to strength training. Additionally, muscle
337 temperature may have increased to a greater degree following netball training, along with
338 induction of post-activation potentiation due to dynamic movements (Turner, Bellhouse,
339 Kilduff, & Russell, 2015), greater than achieved following strength training.

340

341 Prior to commencing the second training session of the day (PreS2), neuromuscular
342 performance was enhanced, and cortisol concentration increased in the NET-STR versus STR-
343 NET trial. Multiple mechanisms may have contributed to the differences in neuromuscular
344 performance observed. Cortisol has been proposed to work in tandem with testosterone to
345 impact neuromuscular performance (Crewther, Obmiński, & Cook, 2018), and may have
346 exerted a positive impact in the present study. The greater volume, intensity or type of exercise
347 performed in netball training could have also led to greater increases in core (Mcgowan et al.,
348 2017) and muscle temperature than that of strength training, resulting in improved
349 neuromuscular function (West et al., 2014). Moreover, repeated high intensity concentric and
350 eccentric contractions involved in strength training could have led to a greater impairment of
351 excitation-contraction coupling compared to netball training, resulting from low-frequency
352 fatigue (McLellan & Lovell, 2012), with exercise-induced muscle damage and damage to type
353 two muscle fibres (Byrne, Twist, & Eston, 2004) contributing to the decrease. Performing
354 subsequent training with impaired neuromuscular performance can impair subsequent training
355 performance (Highton, Twist, & Eston, 2009) and adaptation to training (Jones et al., 2016).
356 Findings therefore suggest that to avoid compromising subsequent training performance,
357 netball training should be performed prior to strength training.

358

359 No differences were observed between trials for external or internal intensity of the netball-
360 training session. Despite reduced neuromuscular performance, prior strength training had no
361 impact upon playing intensity of netball, similar to previously reported in football (Sparkes et
362 al., 2020). Whilst players may have compensated to maintain the required intensity, playing
363 intensity was maintained without any change to heart rate or perceived effort, suggesting that
364 the prior strength training had no effect on subsequent netball-training performance. It should
365 be noted however, that the aims of the netball-training session were technical in nature, and

366 therefore the impact of prior exercise on more maximal type exercise is unclear and warrants
367 further investigation. Perceived technical/cognitive demands of the strength-training session
368 were increased when preceded by netball. Whilst this does not indicate players were overly
369 exerted, coaches and conditioning coaches should be aware of this when planning training and
370 modify technically challenging exercises based on individual player's needs.

371

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

388

389 We acknowledge limitations in this study design. There was no control in place for menstrual
390 cycle phase, or hormonal contraceptive use. However a recent meta-analysis (McNulty et al.,
391 2020) reported a trivial effect of menstrual cycle phase on exercise performance, whilst a
392 previous report in elite female athletes suggest similar patterns in hormonal responses to
393 training and competition with and without hormonal contraceptive use (Crewther, Hamilton,
394 Casto, Kilduff, & Cook, 2015). We also could not randomise training order due to the training
395 commitments of elite players, and numbers of players required for training sessions. We
396 compared players responses to their daily baseline value, rather than between trials, to eliminate
397 circadian rhythm and menstrual cycle influences, players were prescribed the same training in
398 the days before testing across both trials, and all players were familiarised with both session
399 orders. Additionally, whilst players were provided nutritional advice with regards to how to
400 optimally prepare for and recover from training, there were no controls in place to ensure this,
401 particularly on the days prior to testing when players were not performing training as a squad.
402 These are, however, inherent limitations when conducting research in elite athletes.

403

404 **Conclusion**

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

411 **References**

- 412 Baguley, T. (2009). Standardized or simple effect size: What should be reported? *British*
413 *Journal of Psychology*, *100*(3), 603–617. <https://doi.org/10.1348/000712608X377117>
- 414 Bailey, J. A., Gastin, P. B., Mackey, L., & Dwyer, D. B. (2017). The Player Load Associated
415 With Typical Activities in Elite Netball. *International Journal of Sport Physiology and*
416 *Performance*, *12*, 1218–1223. <https://doi.org/https://doi.org/10.1123/ijsp.2016.0378>
- 417 Barrett, S., Midgley, A., & Lovell, R. (2014). PlayerLoad™: Reliability, convergent validity,
418 and influence of unit position during treadmill running. *International Journal of Sports*
419 *Physiology and Performance*, *9*(6), 945–952. <https://doi.org/10.1123/ijsp.2013-0418>
- 420 Birdsey, L. P., Weston, M., Russell, M., Johnston, M. J., Cook, C. J., & Kilduff, L. P. (2019).
421 Neuromuscular, physiological and perceptual responses to an elite netball tournament.
422 *Journal of Sports Sciences*, *00*(00), 1–6.
423 <https://doi.org/10.1080/02640414.2019.1625613>
- 424 Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of MinimaxX accelerometers for
425 measuring physical activity in Australian football. *International Journal of Sport*
426 *Physiology and Performance*, *6*, 311–321. <https://doi.org/10.1123/ijsp.6.3.311>
- 427 Brownstein, C. G., Dent, J. P., Parker, P., Hicks, K. M., Howatson, G., Goodall, S., &
428 Thomas, K. (2017). Etiology and recovery of neuromuscular fatigue following
429 competitive soccer match-play. *Frontiers in Physiology*, *8*(OCT).
430 <https://doi.org/10.3389/fphys.2017.00831>
- 431 Byrne, C., Twist, C., & Eston, R. (2004). Neuromuscular function after exercise-induced
432 muscle damage: theoretical and applied implications. *Sports Medicine (Auckland, N.Z.)*,
433 *34*(1), 49–69. [https://doi.org/https://doi.org/0112-1642/04/0001-0049/\\$31.00/0](https://doi.org/https://doi.org/0112-1642/04/0001-0049/$31.00/0)

- 434 Chandler, P., Pinder, S., Curran, J., & Gabb. (2014). Physical demands of training and
435 competition in collegiate netball players. *Journal of Strength and Conditioning*
436 *Research*, 28(10), 2732–2737. [https://doi.org/10.1519/1533-4287\(2005\)19<202](https://doi.org/10.1519/1533-4287(2005)19<202)
- 437 Crewther, B. T., Cook, C. J., Cardinale, M., Weatherby, R., & Lowe, T. (2011). Two
438 emerging concepts for elite athletes. *Sports Medicine*, 41(2), 103–123.
439 <https://doi.org/10.2165/11536850-000000000-00000>
- 440 Crewther, B. T., Hamilton, D., Casto, K., Kilduff, L. P., & Cook, C. J. (2015). Effects of oral
441 contraceptive use on the salivary testosterone and cortisol responses to training sessions
442 and competitions in elite women athletes. *Physiology and Behavior*, 147, 84–90.
443 <https://doi.org/10.1016/j.physbeh.2015.04.017>
- 444 Crewther, B. T., Obmiński, Z., & Cook, C. J. (2018). Serum cortisol as a moderator of the
445 relationship between serum testosterone and Olympic weightlifting performance in real
446 and simulated competitions. *Biology of Sport*, 35(3), 215–221.
447 <https://doi.org/10.5114/biolSport.2018.74632>
- 448 Crewther, B. T., Sanctuary, C. E., Kilduff, L. P., Carruthers, J. S., Gaviglio, C. M., & Cook,
449 C. J. (2013). The Workout Responses of Salivary-Free Testosterone and Cortisol
450 Concentrations and Their Association With the Subsequent Competition Outcomes in
451 Professional Rugby League. *Journal of Strength and Conditioning Research*, 27(2),
452 471–476. <https://doi.org/10.1519/JSC.0b013e3182577010>
- 453 Doma, K., & Deakin, G. B. (2013). The effects of strength training and endurance training
454 order on running economy and performance. *Applied Physiology, Nutrition and*
455 *Metabolism*, 656(January), 651–656. <https://doi.org/10.1139/apnm-2012-0362>
- 456 Edwards, D. A., & Kurlander, L. S. (2010). Women’s intercollegiate volleyball and tennis:
457 Effects of warm-up, competition, and practice on saliva levels of cortisol and

- 458 testosterone. *Hormones and Behavior*, 58(4), 606–613.
459 <https://doi.org/10.1016/j.yhbeh.2010.06.015>
- 460 Fox, A., Spittle, M., Otago, L., & Saunders, N. (2013). Activity profiles of the Australian
461 female netball team players during international competition: implications for training
462 practice. *Journal of Sports Sciences*, 31(14), 1588–1595.
463 <https://doi.org/10.1080/02640414.2013.792943>
- 464 García-Pallarés, J., Sánchez-Medina, L., Carrasco, L., Díaz, A., & Izquierdo, M. (2009).
465 Endurance and neuromuscular changes in world-class level kayakers during a periodized
466 training cycle. *European Journal of Applied Physiology*, 106(4), 629–638.
467 <https://doi.org/10.1007/s00421-009-1061-2>
- 468 Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative
469 countermovement-jump analysis to quantify acute neuromuscular fatigue. *International*
470 *Journal of Sports Physiology and Performance*, 10(1), 84–92.
471 <https://doi.org/10.1123/ijsp.2013-0413>
- 472 Hawley, J. A. (2009). Molecular responses to strength and endurance training: Are they
473 incompatible? *Applied Physiology, Nutrition and Metabolism*, 34(3), 355–361.
474 <https://doi.org/10.1139/H09-023>
- 475 Highton, J. M., Twist, C., & Eston, R. G. (2009). The effects of exercise-induced muscle
476 damage on agility and sprint running performance. *Journal of Exercise Science and*
477 *Fitness*, 7(1), 24–30. [https://doi.org/10.1016/S1728-869X\(09\)60004-6](https://doi.org/10.1016/S1728-869X(09)60004-6)
- 478 Johnston, M. J., Johnston, J., Cook, C. J., Costley, L., Kilgallon, M., & Kilduff, L. P. (2017).
479 The effect of session order on the physiological, neuromuscular, and endocrine
480 responses to maximal speed and weight training sessions over a 24-h period. *Journal of*
481 *Science and Medicine in Sport*, 20(5), 502–506.

- 482 <https://doi.org/10.1016/j.jsams.2016.03.007>
- 483 Jones, T. W., Howatson, G., Russell, M., & French, D. (2016). Performance and endocrine
484 responses to differing ratios of concurrent strength and endurance training. *Journal of*
485 *Strength and Conditioning Research*, 30(3), 693–702.
- 486 Kilduff, L. P., Finn, C. V., Baker, J. S., Cook, C. J., & West, D. J. (2013). Preconditioning
487 strategies to enhance physical performance on the day of competition. *International*
488 *Journal of Sports Physiology and Performance*, 8(6), 677–681.
489 <https://doi.org/10.1123/ijsp.8.6.677>
- 490 Lepers, R., Maffiuletti, N. A., Rochette, L., Brugniaux, J., & Millet, G. Y. (2002).
491 Neuromuscular fatigue during a long-duration cycling exercise. *Journal of Applied*
492 *Physiology*, 92(4), 1487–1493. <https://doi.org/10.1152/jappphysiol.00880.2001>
- 493 Leveritt, M., Abernethy, P. J., Barry, B. K., & Logan, P. A. (1999). Concurrent strength and
494 endurance training. A review. *Sports Medicine*, 28(6), 413–427.
495 <https://doi.org/10.2165/00007256-199928060-00004>
- 496 McGowan, C. J., Pyne, D. B., Thompson, K. G., Raglin, J. S., & Rattray, B. (2017). Morning
497 Exercise : Enhancement of Afternoon Sprint-Swimming Performance. *International*
498 *Journal of Sports Physiology and Performance*, 12, 605–611.
- 499 McLaren, S. J., Smith, A., Spears, I. R., & Weston, M. (2017). A detailed quantification of
500 differential ratings of perceived exertion during team-sport training. *Journal of Science*
501 *and Medicine in Sport*, 20(3), 290–295. <https://doi.org/10.1016/j.jsams.2016.06.011>
- 502 McLellan, C. P., & Lovell, D. I. (2012). Neuromuscular responses to impact and collision
503 during elite rugby league match play. *Journal of Strength and Conditioning Research*,
504 26(5), 1431–1440.

- 505 McNulty, K. L., Elliott-Sale, K. J., Dolan, E., Swinton, P. A., Ansdell, P., Goodall, S., ...
506 Hicks, K. M. (2020). The Effects of Menstrual Cycle Phase on Exercise Performance in
507 Eumenorrhoeic Women: A Systematic Review and Meta-Analysis. *Sports Medicine*,
508 (0123456789). <https://doi.org/10.1007/s40279-020-01319-3>
- 509 Owen, N., Watkins, J., Kilduff, L. P., Bevan, H., & Bennett, M. (2014). Development of a
510 Criterion Method to Determine Peak Mechanical Power Output in a Countermovement
511 Jump. *Journal of Strength and Conditioning Research*, 28(6), 1552–1558.
- 512 Pek, J., & Flora, D. B. (2018). Reporting effect sizes in original psychological research: A
513 discussion and tutorial. *Psychological Methods*, 23(2), 208–225.
514 <https://doi.org/10.1037/met0000126>
- 515 Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2011). Effect of post-match cold-
516 water immersion on subsequent match running performance in junior soccer players
517 during tournament play. *Journal of Sports Sciences*, 29(1), 1–6.
518 <https://doi.org/10.1080/02640414.2010.512640>
- 519 Russell, M., King, A., Bracken, R. M., Cook, C. J., Giroud, T., & Kilduff, L. P. (2016). A
520 Comparison of Different Modes of Morning Priming Exercise on Afternoon
521 Performance. *International Journal of Sport Physiology and Performance*, 11(6), 763–
522 767.
- 523 Seiler, S., Haugen, O., & Kuffel, E. (2007). Autonomic Recovery after Exercise in Trained
524 Athletes: Intensity and Duration Effects. *Medicine and Science in Sports and Exercise*,
525 39(8), 1366–1373. <https://doi.org/10.1249/mss.0b013e318060f17d>
- 526 Shearer, D. A., Sparkes, W., Northeast, J., Cunningham, D. J., Cook, C. J., & Kilduff, L. P.
527 (2017). Measuring recovery: An adapted Brief Assessment of Mood (BAM+) compared
528 to biochemical and power output alterations. *Journal of Science and Medicine in Sport*,

- 529 20(5), 512–517. <https://doi.org/10.1016/j.jsams.2016.09.012>
- 530 Simpson, M. J., Jenkins, D. G., Scanlan, A. T., & Kelly, V. G. (2020). Relationships Between
531 External- and Internal-Workload Variables in an Elite Female Netball Team and
532 Between Playing Positions. *International Journal of Sports Physiology and
533 Performance*, 15(6), 841–846. <https://doi.org/10.1123/ijsp.2019-0619>
- 534 Sparkes, W., Turner, A. N., Weston, M., Russell, M., Johnston, M. J., & Kilduff, L. P.
535 (2020). The effect of training order on neuromuscular, endocrine and mood response to
536 small-sided games and resistance training sessions over a 24-h period. *Journal of
537 Science and Medicine in Sport*, 23(9), 866–871.
538 <https://doi.org/10.1016/j.jsams.2020.01.017>
- 539 Turner, A. P., Bellhouse, S., Kilduff, L. P., & Russell, M. (2015). Postactivation Potentiation
540 of Sprint Acceleration Performance Using Plyometric Exercise. *Journal of Strength and
541 Conditioning Research*, 29(2), 343–350.
- 542 West, D. J., Cook, C. J., Beaven, M., & Kilduff, L. P. (2014). The Influence of the Time of
543 Day on Core Temperature and Lower Body Power Output in Elite Rugby Union Sevens
544 Players. *Journal of Strength and Conditioning Research*, 28(6), 1524–1528.
545 <https://doi.org/10.1519/R-21636.1>
- 546 Weston, M., Siegler, J., Bahnert, A., McBrien, J., & Lovell, R. (2015). The application of
547 differential ratings of perceived exertion to Australian Football League matches. *Journal
548 of Science and Medicine in Sport*, 18(6), 704–708.
549 <https://doi.org/10.1016/j.jsams.2014.09.001>
- 550 Young, C. M., Gastin, P. B., Sanders, N., Mackey, L., & Dwyer, D. B. (2016). Player load in
551 elite netball: Match, training, and positional comparisons. *International Journal of
552 Sports Physiology and Performance*, 11(8), 1074–1079.

553 <https://doi.org/10.1123/ijssp.2015-0156>

554

555

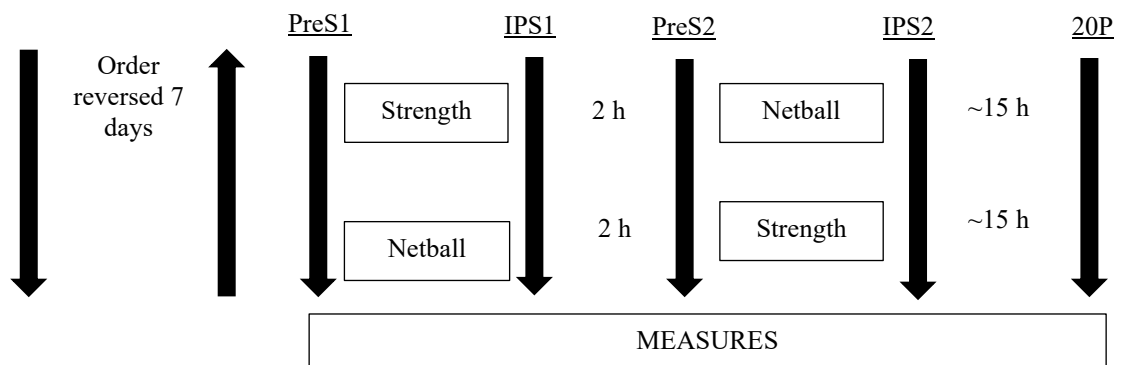
556

557

558

559

560



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

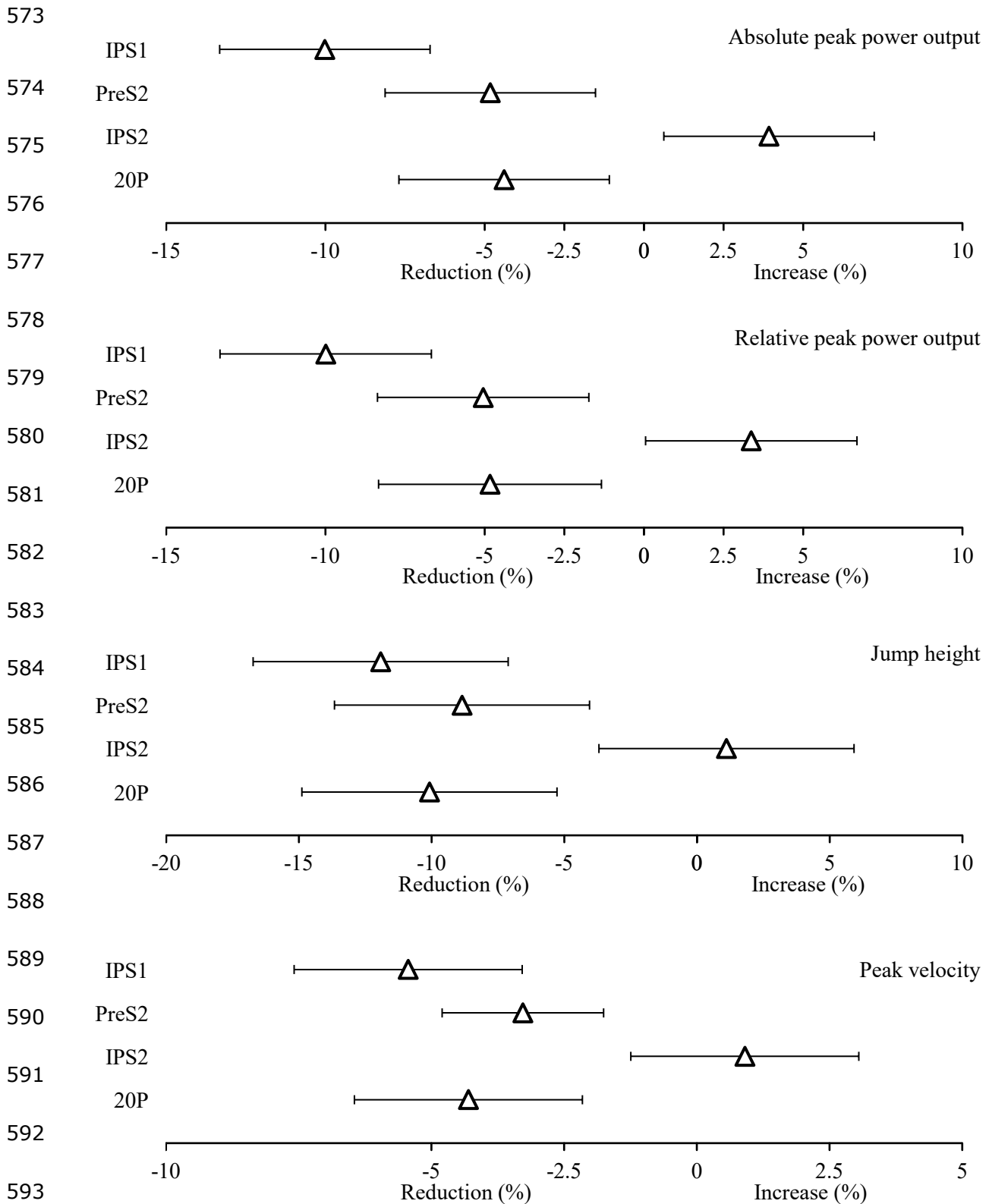
568

569

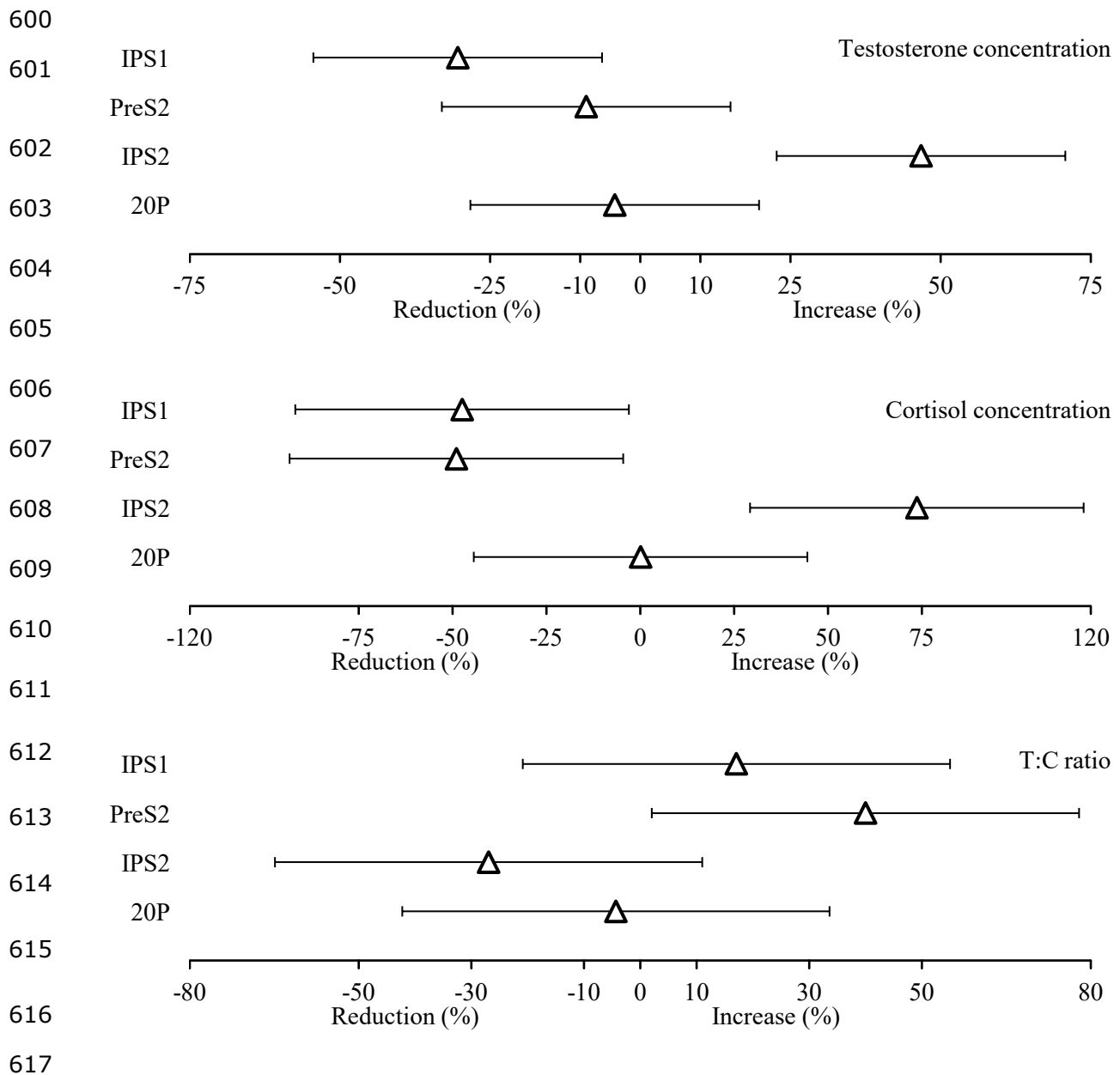
570

571

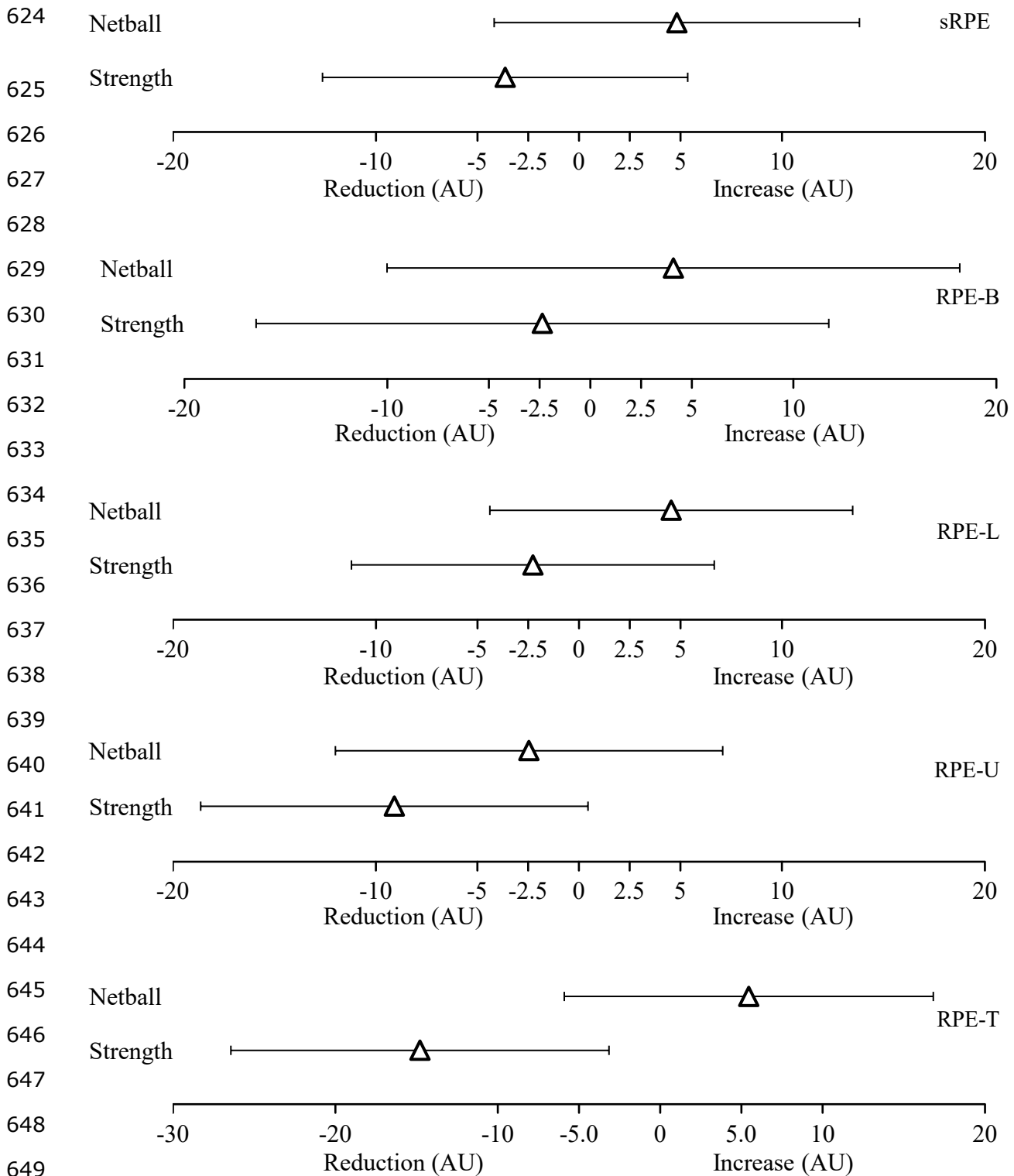
572



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



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



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

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

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

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

666

667

668 **Table 2:** Mean (\pm SD) of internal (mean HR, maximum HR) and external intensity of the
 669 netball-training session, and perception of effort (sRPE, RPE-B, RPE-L, RPE-U, RPE-T) for
 670 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 ($\text{b}\cdot\text{min}^{-1}$)	147 \pm 8	143 \pm 13	-	-
Maximum HR ($\text{b}\cdot\text{min}^{-1}$)	197 \pm 3	197 \pm 3	-	-
External intensity ($\text{AU}\cdot\text{min}^{-1}$)	4.1 \pm 0.4	4.1 \pm 0.5	-	-
sRPE (AU)	58 \pm 9	53 \pm 14	47 \pm 11	51 \pm 12
RPE-B (AU)	48 \pm 12	44 \pm 21	29 \pm 20	31 \pm 14
RPE-L (AU)	49 \pm 15	45 \pm 15	56 \pm 10	59 \pm 8
RPE-U (AU)	29 \pm 11	31 \pm 13	40 \pm 15	49 \pm 10
RPE-T (AU)	52 \pm 11	46 \pm 13	25 \pm 9	40 \pm 18

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

676