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1 **Title: Assessment of Physical demands and Fluid balance in elite female handball**
2 **players during a 6-day competitive tournament**

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25 **Title: Assessment of Physical demands and Fluid balance in Elite Female Handball**
26 **Players During a 6-Day Competitive Tournament**
27

28 **Abstract**

29 Little data exists on drinking behaviour, sweat loss and exercise intensity across a competitive
30 handball tournament in elite female athletes. Heart rate (HR), fluid balance and sweat electrolyte
31 content were assessed on 17 international players across a 6-day tournament involving 5 games
32 and 2 training sessions played indoors ($23 \pm 2^\circ\text{C}$, $30 \pm 2\%$ relative humidity). Active play
33 (effective) mean HR was 155 ± 14 bpm ($80 \pm 7.5\%$ HR_{max}) with the majority of time (64%) spent
34 exercising at intensities $>80\%$ HR_{max} . Mean (*SD*) sweat rates during games was 1.02 ± 0.07 $\text{L}\cdot\text{h}^{-1}$
35 and on 56% of occasions fluid intake matched or exceeded sweat loss. A significant relationship
36 was observed between estimated sweat loss and fluid intake during exercise ($r^2 = 0.121$, $P =$
37 0.001). Mean sweat sodium concentration was 38 ± 10 $\text{mmol}\cdot\text{L}^{-1}$, with significant associations
38 observed between player sweat rates and time spent exercising at intensities $>90\%$ HR_{max} ($r^2 =$
39 0.181 , $P = 0.001$). Fluid and electrolyte loss appear to be work rate dependent in elite female
40 handball players, whom appear well capable of replacing fluids lost within a tournament
41 environment. Due to large between-athlete variations, a targeted approach may be warranted for
42 certain players only.

43 **Introduction**

44

45 Handball is a fast paced body-contact Olympic sport played by two competing teams of 7 players
46 (including a goalkeeper) on an indoor court (40m x 20m) over two 30 minute periods. It is
47 generally recognised that games are played at high-intensity due to the nature of rolling
48 substitutions and recent rule changes on starting the game from the centre after a goal is scored.
49 Despite its popularity, a paucity of data exists to describe the games physical demands. Recent

50research on elite male handballers has shown that players cover a mean distance of 4370 ± 702 m
51during games, most of which is spent performing low-intensity aerobic exercise actions
52interspersed by a short duration of very high-intensity anaerobic actions (Póvoas et al., 2012). In
53the latter study, players were observed to exercise at a mean intensity of $82 \pm 9.3\%$ of HR_{max} . To
54our knowledge, only one study describes the physical demands within the elite women's game
55with players observed to cover distances of 4002 ± 551 m and exercise at high mean relative
56workloads ($79.4 \pm 6.4\%$ VO_2 -max) during match-play (Michalsik et al., 2013).

57

58Handball is played indoors, and although most playing halls have temperature controlled
59environments, high-intensity exercise may result in thermal stress and subsequent disruption of
60body water and electrolyte balance. Team sport players have been shown to lose variable amounts
61of electrolytes in sweat (Kurdak et al., 2010; Maughan et al., 2007b) and the magnitude of solute
62loss appears dependant on both sweat rate and composition. In soccer, large individual variations
63in player sweat response are known to occur as a result of differences in environmental
64temperature and humidity, work-rates, state of acclimation and individual fitness (Maughan,
65Watson, Evans, Broad & Shirreffs, 2007). When exercising in the heat, a 1-3% loss in BM due to
66sweat losses has been reported to result in elevated HR, core temperature (T_c), rating of perceived
67exertion, and plasma osmolality (Mountain & Coyle, 1992; Buono & Wall, 2000). More recently, it
68has been observed that muscle glycogenolysis significantly increases early in exercise with a BM
69loss of $< 2\%$ and this appears related to a rise in core and muscle temperature (Logan-Sprenger et
70al., 2013). However, available data has shown that values in excess of 2% BM are needed before
71aspects of team sport physical and cognitive performance begin to be negatively affected (Baker et
72al., 2007; McGregor et al., 1999). While many studies have investigated fluid balance in team
73sport athletes during practice or competition in the field (Maughan et al., 2005; Kurdak et al.,
742010; Maughan et al., 2007) few, if any, have explored changes in these variables across a

75competitive tournament. In particular, there are no data available on women's handball. Olympic
76handball teams may play up to 5 games in 9 days during group stages of a major competition.
77Since prior hypohydration will amplify the effects of any fluid deficit incurred during exercise,
78added emphasis on fluid-electrolyte replacement may be required during such time periods to
79ensure adequate recovery between games. For this reason, understanding the pattern of fluid and
80electrolytes losses during a tournament may assist with the provision of targeted interventions in
81players with high sweat rates or where failure to replace lost fluids might raise concerns of an
82ergolytic effect.

83

84The main aim of this investigation was to observe normal fluid balance behaviour and quantify
85electrolyte losses across a competitive tournament in a team preparing for the Olympic Games.
86Secondary aims were to describe the physical demands of elite women handball players and
87investigate whether or not fluid-electrolyte losses could be explained from exercise intensity and
88effort distribution.

89**Methods**

90**Participants.** Data were collected on an international team ($n = 17$) of female handball players ($26 \pm$
915 yr, 1.72 ± 0.06 m, 70.7 ± 8.5 kg: mean \pm SD) during a tournament scenario over six days.

92**Experimental design.**

93The team participated in two training sessions and five competitive friendly games against top club
94opposition whom were normally playing at the highest standard in European handball competition
95(Figure 1). Data collection took place at two training venues seven months before the 2012 Olympic
96Games which the team under investigation subsequently participated. Games were played according
97to international handball federation rules and with the exception of game 4 (lasted 90 minutes due to
98a prior agreement between coaching teams), consisted of two periods of 30 minutes. The team

10

99under investigation recorded three wins and two losses during the investigation. Training sessions
100lasted 104 ± 2.1 minutes, consisting of warm-up, calisthenics, position-specific drills, small-sided
101games and technical drills. Environmental conditions during the games/training sessions are shown
102in Table 1 and all measurements were recorded with a portable thermohygrometer (Higbo, Oregon
103Scientific, Berkshire, UK).

104 Study approval was obtained from the national governing body involved and collection of data
105arose as part of the service provision supplied to the team in preparation for competition (Winter &
106Maughan, 2009). All athletes agreed to take part and signed consent was obtained. To ensure player
107confidentiality, data were anonymized before analysis.

108

109**Testing procedures** Players wore shorts and short sleeve T-shirts throughout testing. On the
110morning of training or games, players provided a urine sample (first void) into a pre-labelled urine
111collection pot (60 ml, Greiner Bio-One Ltd, Stroud, UK). Urine refractive index (Pocket
112Osmocheck, Vitech Scientific Ltd, Sussex, UK) were subsequently determined to provide an index
113of pre-exercise hydration status (Shirreffs, 2003; Sparks and Close, 2012). Players were provided
114with dietary plans by the affiliated nutritionist in the lead up to training/games. As per norm, food
115was self-prepared in large player groups within nearby shared accommodation to the team home
116venue and this was not altered during the investigation. Neither dinner nor breakfast was recorded
117or standardized so as to avoid interference with player's normal dietary/fluid habits. Player
118menstrual state was not recorded during the 6-day tournament.

119Over a 15-min period (-45 to -30 min) before the start of each game/training, players were weighed
120(nude) to the nearest 20 g on a calibrated electronic scale (Marsden W/M, Oxford, UK). After entry
121to the playing court, players were fitted with a heart rate (HR) strap and individual HR data was
122subsequently collected wirelessly at one-second intervals (Polar Team System, Polar Electro,

123Kempele, Finland). Following team warm-down, players were re-weighed (toweled dry nude) on
124the same calibrated scale. Body mass changes were used as a proxy measure for sweat losses. While
125this represents a limitation of the study, previous work has indicated that this represents a realistic
126field measurement to estimate hypohydration (Maughan et al., 2007a). Players were asked to refrain
127from eating between weighing points but were free to drink fluids *ad libitum* and whenever breaks
128in play were permitted (1 minute time-out per-half is allowed by handball rules). Players were asked
129to consume drink products which they would normally consume during everyday practice and
130games. This included either tap water or tap water mixed with sugar free cordial for the current
131player group. Observed checks confirmed that no player consumed commercial drink products or
132electrolyte sachets during exercise. Therefore electrolyte intake during sessions/games was
133considered negligible.

134All bottles were individually numbered and players drank from bottles assigned to them by team
135staff. All players were left to behave as they wished with regard to fluid consumption. During the
136time period from weighing players before and after exercise, each player's fluid intake was
137measured to the nearest 0.001kg on a calibrated scale (Adam Equipment Ltd., Milton Keynes, UK).
138A volume of 1 mL ingested fluid was assumed to weigh 1 g. In the event of players wishing to
139urinate during the analysis period, they were accompanied by research staff to the toilet and
140provided with a pre-weighed urine collection bag with funnel (P-Bag, Medipost Ltd, Dorset, UK).
141Filled urine collection bags were subsequently weighed to aid in determination of fluid balance. All
142bottles/collection devices were weighed out of view of the players at all times.

143

144*Sweat collection and analysis*

145Before three of the five games, players were prepared for sweat sample collection using methods
146outlined previously (Maughan et al., 2007b; Maughan & Shirreffs, 2008). Briefly, players had

147absorbent patches (Tegaderm + pads, 3M, Loughborough, UK) placed on four body locations
148(chest, upper forearm, back and thigh). Before attaching patches to the skin, the locations were
149washed thoroughly with deionized water and dried with electrolyte-free gauze. At the end of each
150game, patches were removed with sterile forceps and each patch was subsequently placed into pre-
151weighed screw-top containers (20 ml, Sterlin, Cambridge, UK) until analysis. No patch showed
152signs of undue saturation (e.g. dripping) across the period of investigation. Following collection,
153samples were stored at 4°C before analysis (within one week of collection).

154To determine electrolyte concentrations, each sweat patch and container were weighed to the
155nearest 4 decimal places before 1 mL of deionized water was added. After mixing, the sample was
156analysed for sodium and potassium concentration using flame photometry (Sherwood 410,
157Sherwood Scientific, Cambridge, UK) and for chloride concentration using the mercuric thiocyanate
158method (Randox, Crumlin, UK). All samples were analysed in duplicate and intra-run coefficients
159of variations were <5%.

160

161*Heart rate data*

162Player heart rate max data (HR_{max}) was obtained in the weeks leading up to experimentation using
163an incremental running test to exhaustion (Yo-Yo IE2 test) conducted by strength and conditioning
164staff. Confirmatory HR_{max} analysis was achieved by comparing these results to those achieved
165previously (-4 months) using a laboratory incremental test to exhaustion. Previous work has shown
166that no systematic differences occur between HR_{max} achieved using the Yo-Yo IE2 test and
167incremental treadmill test in intermittent sport (Bradley et al., 2011).

168Heart-rate readings were classified into 5 intensity zones, ranging from 50-59%, 60-69%, 70-79%,
16980-89% and 90-100% HR_{max} for assessment of physiological load in team handball (Póvoas et al.,

1702012). The percentage of time spent exercising in each zone was determined to provide an
171indication of exercise intensity for each player and all HR values were analysed during the first and
172second halves. Given that team handball rules allow for unlimited substitutions, it is unusual that
173one athlete plays an entire game. Furthermore, a one-minute time-out period is allowed for each
174team per-half. Therefore, HR during the games were analysed (a) as total HR (i.e. HR during the
175total game time) to provide an index of global cardiovascular load and (b) HR during active play
176time (effective HR) in order to classify game demands during time when a player was actually on
177the playing court (Póvoas et al., 2012). The time period for the half-time break was excluded from
178HR analysis.

179Calculations

180Sweat rate (SwTR: L·h⁻¹) was estimated as net body mass loss (kg) during the training session/game
181plus the total fluid intake divided by the exercise time (min). Corrections for any individual player
182urine loss were also made.

$$183\text{SwTR} = \{[\text{pre-exercise mass (kg)} - \text{post-exercise mass (kg)}] - \text{urine volume (L)} + \text{fluids consumed (L)}\} / \text{time (h)}.$$

184Fluid intake (L·h⁻¹) was calculated as total fluid intake during the recorded exercise session divided
185by the exercise time (per hour). Changes in BM before and after exercise were to assess acute
186changes in hydration status (% fluid deficit). Net balance of respiratory and metabolic contributions
187to BM loss was considered negligible as observed previously under similar environmental
188conditions for indoor team sport (Hamouti et al. 2010). Sweat electrolyte losses (in grams) were
189calculated from the sweat electrolyte concentration, the molecular weight of the electrolyte, and the
190total sweat loss of the individual (Maughan et al., 2007a). It was assumed that the mean sodium
191concentration (from 4 collected sites) represented mean whole-body sodium concentration although
192it is acknowledged that this may be an overestimate (Shirreffs & Maughan, 1997).

193Statistical analysis

194Data sets were initially tested for normality of distribution using the Shapiro–Wilk test.
195Comparisons between data were then made using paired t-tests and a one-way repeated measures
196analysis of variance (ANOVA). Differences in regional sweat electrolyte concentration were
197determined by 1-way ANOVA and with Tukey’s test of honestly significant difference.
198Relationships between parameters were performed using a least-squares regression model, and the
199coefficient of determination (r^2) is reported (Maughan et al, 2005). All statistical analyses were
200performed using SPSS v. 20. Data are presented as mean \pm standard deviation (SD) with range of
201data given in parentheses. Statistical significance was set at $P < 0.05$.

202

203

204Results

205

206Heart rate

207

208Player HR_{max} achieved during incremental running test was $191 \pm 7 \text{ bpm}^{-1}$. Peak HR over the 5
209games ($182 \pm 9 \text{ bpm}^{-1}$; $93 \pm 5\%$ of HR_{max}) was significantly higher than values recorded in training
210($169 \pm 13 \text{ bpm}^{-1}$; $86 \pm 5\%$ of HR_{max}); $P < 0.05$. Player effective mean HR ($155 \pm 14 \text{ bpm}^{-1}$; $80 \pm 8\%$
211of HR_{max}) was also significantly higher than values observed in training ($129 \pm 10 \text{ bpm}^{-1}$; $65 \pm 5\%$
212of HR_{max}) and total mean game HR ($131 \pm 14 \text{ bpm}^{-1}$) ($P < 0.05$). Average time spent by players in
213“active” play during games was 33 ± 15 minutes.

214

215No between game-half differences were observed for either total or effective mean player HR
216(Figure 2). Furthermore, no significant differences were observed between game halves at different
217interval percentages of players’ HR_{max} (Figure 3). The majority of effective game time (64%) was
218spent exercising at intensity $>80\%$ HR_{max} , with 23% of game time spent exercising $>90\%$ HR_{max} . No
219between game differences were observed for percentage of effective or total game time spent any of
220the designated HR zones.

221

222

223 *Morning hydration status*

224

225 On the mornings of the games, 47% of players awoke with a urine refractive index ≥ 700
226 mOsmol/kg. No relationship was observed between previous days fluid intake during exercise and
227 the following mornings urine refractive index ($P = 0.116$). Furthermore, no relationship was
228 observed between morning urine refractive index and subsequent fluid intake during exercise, ($r^2 =$
229 0.014; $P = 0.307$; Figure 4a). A significant relationship was observed between morning urine
230 refractive index and percentage change in player BM during training/games ($r^2 = 0.159$; $P = 0.001$),
231 Figure 4b. No between game differences in morning measures of hydration status were observed
232 (Figure 6).

233

234

235 *Fluid balance*

236 Across the games, mean team fluid intake was 1.05 ± 0.16 L. After correction for amount of fluid
237 ingested, estimated mean team fluid loss was 1.08 ± 0.18 L. A significant relationship was observed
238 between fluid intake during exercise and estimated fluid (sweat) loss ($r^2 = 0.0121$; $P = 0.001$; Figure
239 5). Fluid intake (L) was significantly lower during training sessions in comparison to games 2, 3
240 and 4 ($P < 0.001$) (Figure 6). Between game comparisons indicated that players consumed
241 significantly more fluid during game 4 than games 2 and 5. Larger volumes of fluids were also
242 consumed during game 3 in comparison to game 5 ($P < 0.001$).

243

244 Mean player sweat rates during games (1.02 ± 0.07 L·h⁻¹) were significantly higher than those
245 observed during training (0.56 ± 0.15 L·h⁻¹) despite similar environmental temperatures ($P < 0.05$;
246 Table 1). No between game differences were observed. A relationship was observed between
247 individual player sweat rates (L·h⁻¹) and time spent exercising at intensities $>90\%$ HR_{max} ($r^2 = 0.181$;
248 $P = 0.001$). During games, 51% of players had a sweat rate < 1 L·h⁻¹ and 47% had a sweat rate

249between 1 and 2 L·h⁻¹. Only on two occasions did player sweat rates exceed 2 L·h⁻¹ during games.
250In contrast, all players had sweat rates < 1 L·h⁻¹ during training. A large inter-individual variability
251was observed in sweating response between players (Figure 5).

252
253

254On 56% of occasions, player fluid intake matched or exceeded fluid (sweat) loss. Sweat loss was
255significantly higher during game 4 than training sessions and game 2 (P < 0.05), game 3 and 5 (P <
2560.01). Across the five games, 43% of players lost body mass (BM) as a result of exercise with most
257(36%) of the group recording losses of <1% BM. In turn, 7% of the player group recorded a loss of
258>1% BM and no player was dehydrated >2% of BM. Conversely, 6% of the players gained more
259than 1% in BM across the games. On average, 0.0 ± 0.1% and 0.1 ± 0.1% net fluid deficits were
260recorded following games and training respectively.

261
262

263 *Electrolyte balance*

264

265The mean (4 site) sweat sodium, chloride and potassium concentrations were 38 ± 10 mmol·L⁻¹, 27
266± 11 mmol·L⁻¹ and 5 ± 1 mmol·L⁻¹, respectively (Table 2). No significant effects for time (between
267games) were observed for sweat sodium, chloride or potassium content (P > 0.05). Mean sodium
268content of sweat in game 4 was significantly higher than game 5 (P < 0.01) while higher sweat
269chloride content was also observed in game 4 compared to game 2 and game 5 (P = 0.03). Sodium
270concentrations in the sweat patches of the 'back' torso were lower compared to all other sites (P <
2710.001). Higher 'arm' chloride concentration was observed in comparison to values recorded from
272players 'back' and 'thigh' (P < 0.001). In turn, chest chloride concentrations were higher than both
273'back' and 'thigh' samples (P < 0.001). Arm potassium concentrations were higher than back, chest
274and thigh concentrations while thigh concentrations were higher than back and chest (P < 0.001;
275Table 2). No association was observed between mean player sweat sodium concentration and sweat
276rate (r² = 0.001; P = 0.57).

277

278 A significant correlation was observed for total sodium loss (1.03 ± 0.43 g) and percentage of time
279 spent by players exercising between 90-100% HR_{max} ($r^2 = 0.210$; $P = 0.016$).

280

281 Discussion

282

283 The aim of this investigation was to assess fluid balance behaviour and determine electrolyte losses
284 across a competitive tournament in elite female handball players. Secondary aims were to assess
285 physical demands and whether or not observed changes in the above variables could be explained
286 from player exercise intensity data.

287

288 While a limited number of studies have documented intensity of exercise in elite men's handball, to
289 date, only one study has been carried out in the elite women's game (Michalsik et al., 2013).
290 Present data shows that female players exercise at a similar mean intensity (155 ± 14 bpm^{-1} ; $80 \pm$
291 18% of HR_{max}) to their elite male counterparts (Chelly et al., 2011; Póvoas et al., 2012) and that the
292 majority of time (64%) is spent performing movements at high $>80\%$ HR_{max} exercise intensities. As
293 expected, mean exercise HR was considerably higher during competition in comparison to those
294 observed in training sessions. This was due to the fact that the coaches used the training sessions
295 with a tactical focus and structured lower intensity than normal to ensure players were not fatigued
296 during the tournament. However, team HR values did not decrease during the second-half of games
297 as observed previously in the elite men's game (Póvoas et al., 2012). In the latter study, modest
298 average relative body weight losses ($0.9 \pm 0.3\%$) were recorded. This, combined with data from the
299 current study ($0.0 \pm 0.1\%$ fluid deficit), suggests that factors other than dehydration may have be
300 responsible for any observed drop off in exercise intensity in Handball. Although dehydration due
301 to sweat loss is a known factor which can impair exercise performance (Coyle, 2004); other factors
302 such as game rotation strategy, score differential, physiological or physical factors may all

303 contribute to game fatigue. It should also be noted that HR data only provides an indication of
304 cardiovascular demands and time-motion characteristics should be studied to better understand how
305 fatigue affects movement patterns.

306

307 In the current study, player sweat rates ($1.02 \pm 0.07 \text{ L}\cdot\text{h}^{-1}$) were similar to the ones observed in
308 female basketball players (Brandenburg & Gaetz, 2012), indoor male handball ($1.1 \pm 0.3 \text{ L}\cdot\text{h}^{-1}$) and
309 volleyball ($1.2 \pm 0.3 \text{ L}\cdot\text{h}^{-1}$) players but considerably lower than indoor soccer ($1.8 \pm 0.7 \text{ L}\cdot\text{h}^{-1}$)
310 (Hamouti et al., 2010). However, a large inter-individual variability (range 0.26-2.1 L) was
311 observed, as noted previously (Maughan et al., 2007b; Hamouti et al., 2010). This, taken together
312 with the large variability in fluid intake across the investigation (range 0.25-2.74 L) highlights the
313 need for individualized assessment of fluid balance strategies in a team sport environment
314 (Shirreffs, Sawka & Stone, 2006). With respect to the current athlete group, it was noted that 6% of
315 players gained more than 1% in body mass (BM) by the end of the games, suggesting that some
316 players might consume excessive fluids. Overall, 56% of players either maintained or increased
317 their BM at the end of the game and this was particularly evident for goalkeepers and rolling
318 substitutes, some of whom consistently consumed more fluids than were lost in sweat. This was
319 most likely due to increased time available on the bench and ease of access to drinking bottles.
320 During handball competition, BM has to be moved against gravity and theoretically an increase in
321 BM from resultant fluid intake might have negative effects on performance in particular when
322 fatigue develops.

323

324 It has been reported that as little as a 2% loss in BM due to dehydration affects many physiological
325 factors thought to indirectly affect performance. These include elevations in HR, core temperature
326 (T_c), rating of perceived exertion (Montain & Coyle, 1992; Buono & Wall, 2000) and muscle
327 glycogenolysis (Logan-Sprenger et al., 2012). In this study, no player was dehydrated $>2\%$ BM

328despite moderate to high sweat rates in some players. The most recent position stand from the
329American College of Sports Medicine (Sawka et al., 2007) has suggested that fluid intake during
330prolonged exercise should be sufficient to limit any BM loss to <2% of pre-exercise mass and that
331athletes should never drink so much that they gain BM during exercise. Therefore, the female
332handball players observed in this study appear to adequately replace fluids lost during exercise, and
333in some cases, education around the risks of overconsumption of fluids is warranted.

334

335Across the six-day tournament, 54% of players awoke with a urine refractive index of <700
336mOsmol/kg or a urine specific gravity <1.020, values previously suggestive of euhydration (Sawka
337et al. 2007). Research has reported that 91% of elite male athletes from a number of indoor team
338sports awoke in hypohydrated state before practice (Hamouti et al., 2010). Therefore, data is
339suggestive that fluid management following exercise appeared adequate in the current player group.
340Start time of training and games varied considerably between days and no difference in markers of
341hydration status was observed between sampling points. It is possible that given the elite nature of
342the current team and the tournament scenario, players were proactive in making sure to replace lost
343fluids during exercise. Alternatively, it is possible that fluid replacement strategies were altered by
344players as a result of been observed during the experimentation period. However, given that study
345experimenters were familiar with players and training environment prior to experimentation, the
346repeated observations and failure to identify trends in fluid intake across the study period; it does
347not appear that this was the case. It should be noted a small number of players (8%) consistently
348provided urine samples that were indicative of being very dehydrated (1.000-1.1290 mOsmol/kg;
349Armstrong et al., 2010) suggesting the need for targeted fluid replacement in such a player group.
350There is some evidence of a positive correlation between pre-training urine osmolality and the
351volume of fluid ingested during a training session where fluids are freely available (Maughan et al.,
3522005). Therefore, athletes who begin training with higher urine osmolality/specific gravity may be

353likely to drink more due to a greater sensation of thirst. In the current study, no relationship was
354observed between morning urine measures and subsequent fluid intake. Such findings have been
355observed previously (Maughan et al., 2007b) and may be dependent on the time period from
356morning hydration assessment and exercise onset. In this study, some games started at 3 pm and so
357it is feasible that athletes had adequate time to correct any fluid imbalance through normal sensory
358means. Unlike previous findings (Maughan et al., 2007b; Hamouti et al., 2010), a modest but
359positive association was observed between the amount of sweat lost and volume of fluid consumed
360(Greenleaf, 1982), indicating that sensation of thirst and ample fluid breaks was capable of
361offsetting major disturbances in fluid balance. Further work should be carried out to determine the
362strength of this relationship in athlete groups whom display a wide range in sweat rates.

363

364Data from tennis (Bergeron, 2003) and American football (Stofan et al., 2005; Horswill et al.,
3652009), have suggested that athletes who sweat profusely and have a high sweat sodium
366concentration may be more likely to experience muscle cramps. However, few if any studies have
367investigated whether or not electrolyte losses vary throughout a condensed tournament environment
368when replacement of salts lost in sweat may be of added importance to the recovery process. In the
369current study, mean sweat electrolyte concentrations were on the lower end of those reported
370previously (Maughan et al., 2005; Hamouti et al., 2010). Very few studies have investigated
371electrolyte losses in elite female athletes (Kilding et al., 2009) and it is possible that gender
372differences may account for observed differences. Although speculative, given that players in this
373study voluntarily chose to consume plain water during exercise, it is also possible that this may, in
374part, account for the lower mean sweat sodium ($38 \pm 10 \text{ mmol.L}^{-1}$) concentrations observed (Sigal
375& Dobson, 1968). A large inter-individual variation was observed for all sweat electrolyte
376concentration (Table 2.) as noted elsewhere (Maughan et al., 2007b). Given that players were rather
377homogenous in terms of fitness level (had similar daily exercise programs), dietary intake (same

378 food menus) and degree of acclimation, it's possible that genetic factors may underpin this finding.
379 As observed previously, no relationships were found between whole body sweat rate and sweat
380 concentration of any electrolyte (Maughan et al., 2007b; Kilding et al., 2009). This is in contrast to
381 recent data in tennis which suggests sweat sodium concentration is related to an individual athlete's
382 sweat rate (Bergeron, 2014). Given that a significant correlation did exist between player sweat
383 rates and time spent exercising at higher intensities, present data are suggestive that time exposure
384 to intense exercise may, in part, have a role in overall electrolyte loss (Hamouti et al., 2011).

385

386 Regional differences in sweat electrolyte composition were observed as previously reported
387 (Maughan et al., 2007b). In this study, lower back torso sodium concentrations were observed
388 compared with other collection sites. These findings are in contrast to previous work carried out on
389 male cyclists (Patterson, Galloway & Nimmo, 2000) and both male and female athletes cycling in
390 a heat chamber (Baker et al., 2009). Future studies should be carried out on female athletes
391 undertaking differing exercise modes to explore further why such regional differences occur. While
392 previous studies which have primarily focused on either once off sweat composition measurements,
393 the current study assessed electrolyte losses across three games in a six-day tournament. Results
394 showed that with the exception of game 4, electrolyte concentrations in sweat were consistent
395 between games. With respect to game 4, both teams agreed to play across 3 x 30 minute period (90
396 minutes total) for technical development reasons. Although between game sweat rates did not differ
397 in this study and stability of electrolyte concentration has been observed across varying exercise
398 durations (Montain, Chevront, & Lukask., 2007), current data suggests that length of sweat patch
399 sampling time does need to be taken into account when assessing electrolyte loss in athletes. A
400 significant association was observed for total sodium deficit (1.03 ± 0.43 g) and per-cent change in
401 BM. Although statistically significant, only a moderate correlation was observed ($r^2 = 0.367$) which,
402 perhaps is not surprising given that salt losses through exercise are influenced by *both* sweat loss

403and electrolyte concentration. Although moderate sodium deficits were incurred, a large variability
404in sodium loss was observed (range: 0.3-2.37 g). Given that the current player group refrained from
405consuming electrolytes during exercise, recommendations to a few select individuals (whom
406experienced high sodium losses) on consumption of electrolyte containing beverages during
407exercise to may be required reduced the sodium deficit and to better retain ingested fluid. This may
408be particularly relevant during a tournament scenario where players have a game every other day.

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410Present results indicate that moderate sweat and electrolyte losses occur during handball games
411played in temperate conditions and the magnitude of such losses appear related to time spent
412exercising at higher intensities. Furthermore, it seems evident that specific approaches need to be
413considered for certain individuals, not only to minimise fluids losses but also to avoid
414overconsumption of fluids which might have negative effects on performance. Lastly, our data
415seems to suggest that the cardiovascular demands of handball games in women are similar to those
416reported for men, albeit further studies are needed to quantify time-motion characteristics of elite
417women's handball.

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526**527 Tables**

528

529 Table 1. Environmental conditions: Temperature (°C) and relative humidity (%) taken at 15 min intervals during the
530 games.

531

532 Table 2. Between game comparison of sweat electrolyte concentrations (mmolxL⁻¹) per collection site. *Significantly
533 different from game 4, P < 0.05. # Significantly different from game 5, P < 0.05.

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535 Figures

536

537 Figure 1. Testing schedule across the tournament.

538

539 Figure 2. Mean and maximal total and effective HR during the first and second halves and total match time. Data
540 presented as absolute and relative to individual maximal HR values (means ± SD). * Significantly different from total
541 HR (P = 0.00). Inset showing effective and total HR data recorded during training.

542

543 Figure 3. Percentage of effective match time spent at different interval percentages of player maximal HR in the first
544 and second halves. Values are means ± SD.

545

546 Figure 4(a). Relationship between measured pre-exercise urine refractive index and measured fluid intake during
547 training/games, $r^2 = 0.014$, $P = 0.307$.

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549 Figure 4(b). Relationship between morning urine refractive index and percentage change in player body mass during
550 training/games, $r^2 = 0.159$, $P = 0.001$.

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552 Figure 5. Relationship between volume of fluid consumed during training/games and the amount of sweat loss (L), $r^2 =$
553 0.121, $P = 0.001$.

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555Figure 6. Rate of fluid intake and sweat loss in players across the tournament. * Significantly higher than training
556sessions (P<0.05). Morning urine refractive index values per game throughout tournament also provided. Values are
557mean \pm SD.

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Table 1. Environmental conditions: Temperature (°C) and relative humidity (%) taken at 15 min intervals during games

	Game 1	Game 2	Game 3	Game 4	Game 5	Training*
Temperature (°C)	21 ± 0	25 ± 0	24 ± 0	22 ± 2	21 ± 1	23 ± 2
Relative humidity (%)	30 ± 2	27 ± 1	30 ± 1	33 ± 2	27 ± 3	31 ± 0

Data are mean ± SD. *Averaged data from two training sessions at same venue.

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564**Table 2.** Between game comparison of sweat electrolyte concentrations (mmol·L⁻¹) per collection site. (SD): standard deviation.

	Game 2		Game 4		Game 5			
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Mean Sodium	36 (13)	19-70	40 (8)	27-54	*35 (7)	24-47	38 (10)	23-57
Arm	38 (14)	16-60	44 (12)	29-67	39 (13)	18-61	41 (13)	16-66
Chest	40 (14)	16-55	46 (11)	23-64	*40 (10)	24-54	42 (12)	16-65
Back	31 (12)	14-60	33 (10)	17-46	*27 (7)	14-40	31 (10)	14-60
Thigh	36 (15)	19-75	42 (11)	26-70	38 (8)	24-48	39 (12)	19-75
Mean Chloride	*24 (16)	2-54	31 (9)	16-47	*25 (8)	15-37	27 (11)	11-46
Arm	*26 (16)	2-50	33 (14)	12-58	31 (12)	16-52	30 (15)	3-57
Chest	*29 (18)	2-55	38 (11)	19-53	*33 (10)	21-46	34 (13)	3-55
Back	20 (13)	2-27	24 (10)	8-40	20 (9)	9-35	22 (11)	2-47
Thigh	*20 (15)	6-52	27 (11)	10-46	*21 (8)	6-33	23 (11)	6-52
Mean Potassium	5 (2)	3-7	6 (1)	4-7	*5 (1)	3-7	5 (1)	3-7
Arm	*6 (2)	3-9	8 (2)	5-12	7 (3)	3-12	7 (2)	3-12
Chest	5 (0)	4-5	5 (1)	3-6	*4 (1)	2-5	4 (1)	2-6
Back	4 (1)	2-6	5 (1)	4-7	*5 (1)	3-6	5 (1)	2-7
Thigh	*6 (1)	5-8	7 (3)	3-14	*5 (1)	3-6	6 (2)	3-14

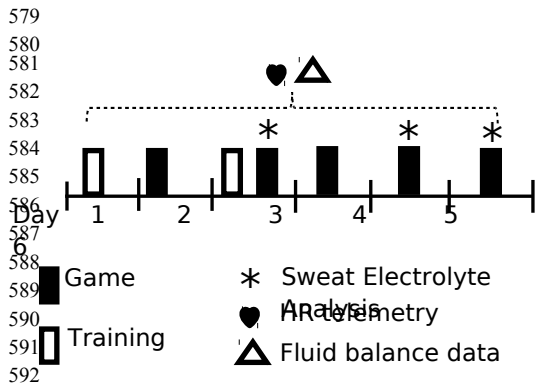
*Significantly different from game 4, P < 0.05. * Significantly different from game 5, P < 0.05.

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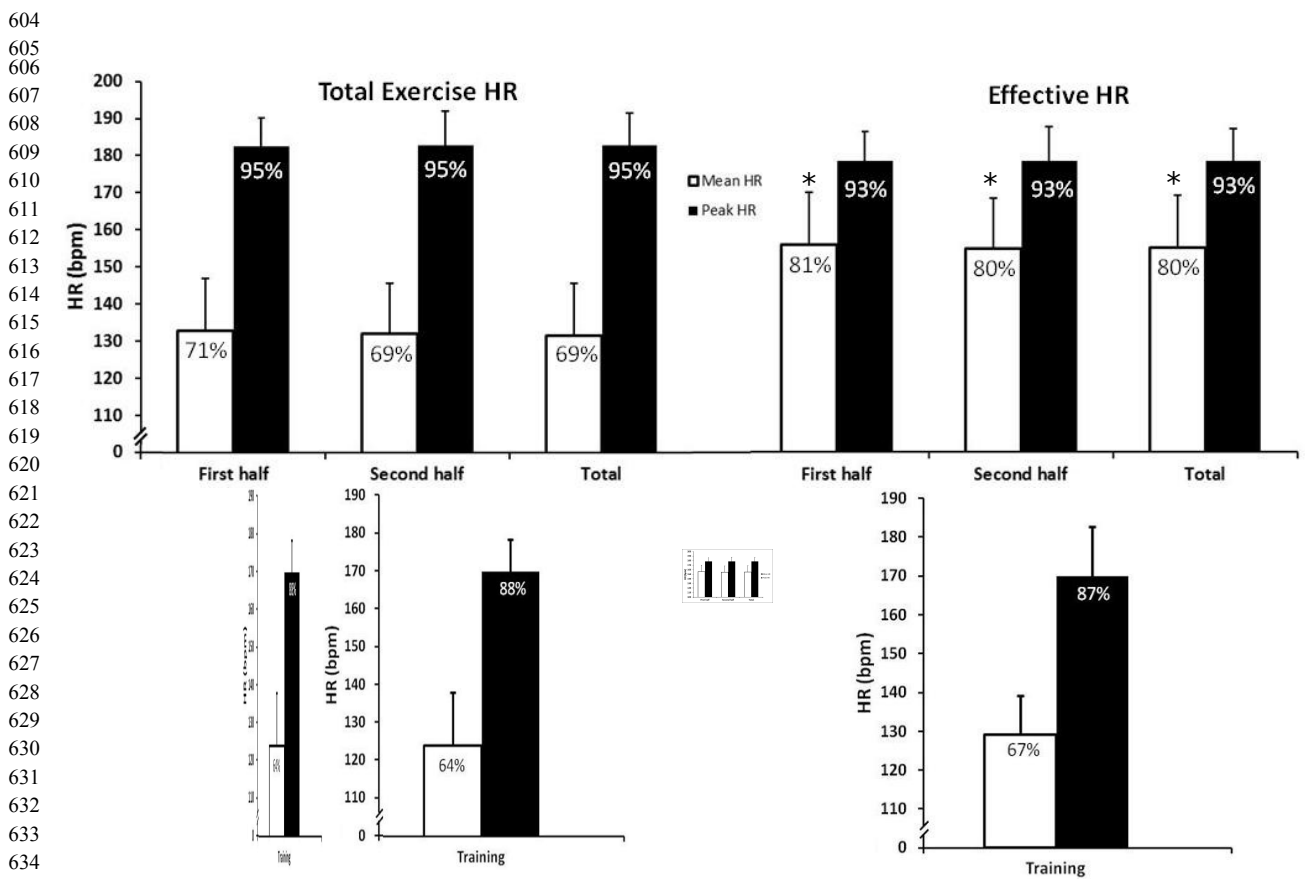
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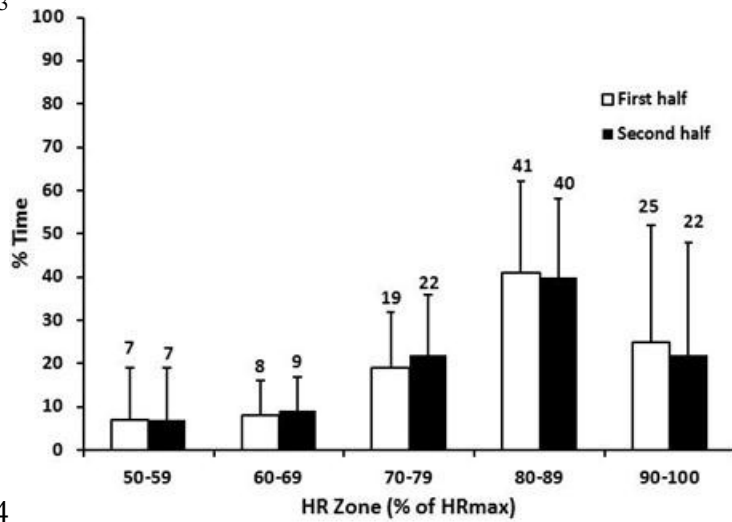


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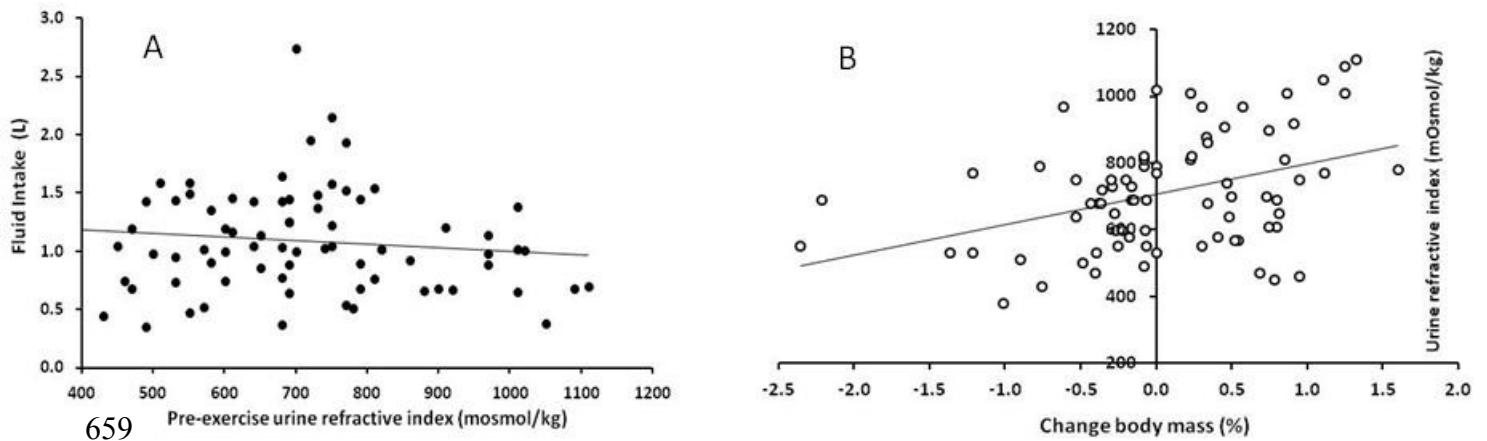


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657 Figure 4

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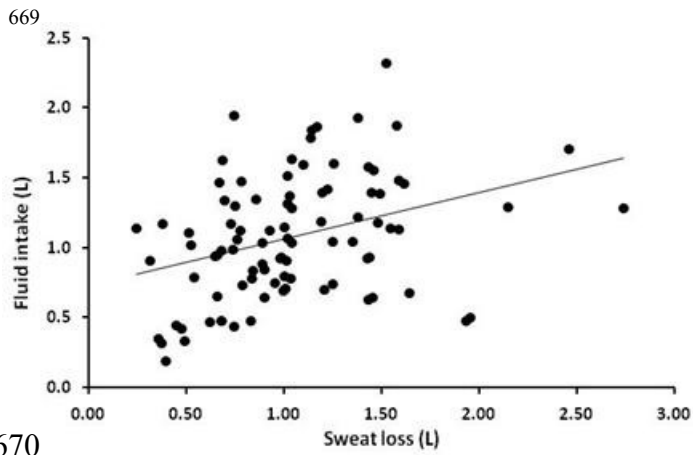
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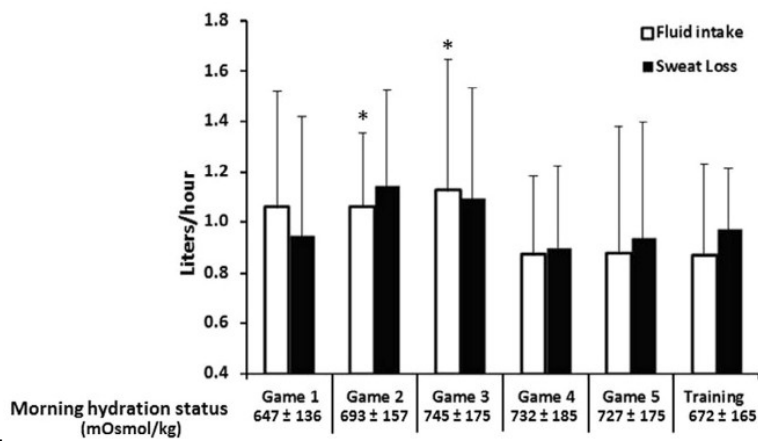


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673 Figure 6



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