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Effects of age and spa treatment on match running performance over two consecutive games in highly trained young soccer players

MARTIN BUCHHEIT, COSMIN HOROBEANU, ALBERTO MENDEZ-VILLANUEVA, BEN SIMPSON, & PITRE C. BOURDON

Physiology Unit, Sports Science Department, ASPIRE, Academy for Sports Excellence, Doha, Qatar

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Abstract

The aim of this study was to examine the effect of age and spa treatment (i.e. combined sauna, cold water immersion, and jacuzzi) on match running performance over two consecutive matches in highly trained young soccer players. Fifteen pre- (age 12.8 ± 0.6 years) and 13 post- (15.9 ± 1 y) peak height velocity (PHV) players played two matches (Matches 1 and 2) within 48 h against the same opposition, with no specific between-match recovery intervention (control). Five post-PHV players also completed another set of two consecutive matches, with spa treatment implemented after the first match. Match running performance was assessed using a global positioning system with very-high-intensity running (> 16.1–19.0 km · h^{-1}), sprinting distance (>19 km · h^{-1}), and peak match speed determined. Match 2 very-high-intensity running was "possibly" impaired in post-PHV players (–9 ± 33%; ± 90% confidence limits), whereas it was "very likely" improved for the pre-PHV players (+27 ± 22%). The spa treatment had a beneficial impact on Match 2 running performance, with a "likely" rating for sprinting distance (+30 ± 67%) and "almost certain" for peak match speed (+6.4 ± 3%). The results suggest that spa treatment is an effective recovery intervention for post-PHV players, while its value in pre-PHV players is questionable.

Keywords: *Football, recovery strategies, hydrotherapy, cold water immersion, adolescents*

Introduction

Competition schedules for team sports such as soccer often require teams to play matches with only a few days of recovery in between (Andersson et al., 2008; Odetoyinbo, Wooster, & Lane, 2007; Spencer et al., 2005). When the time between matches is limited, residual fatigue accumulated over successive matches can adversely affect physical performance (Andersson et al., 2008; Odetoyinbo et al., 2007; Spencer et al., 2005). For example, high-intensity activities during matches tended to decrease in elite adult soccer players who played three matches within 5 days (Odetoyinbo et al., 2007). In adult field-hockey players, reduced repeated-sprint ability was reported during match-play involving three matches within 4 days (Spencer et al., 2005). Nevertheless, previous studies have focused only on adult team sport players and effects of age on match-related fatigue accumulation are unknown. Young players, especially those before and during puberty, are known either to resist or delay fatigue better than adolescents and adults during repeated high-intensity exercise bouts (Ratel, Duche, & Williams, 2006). This is of interest in soccer, as these high-intensity activity patterns are an integral part of the physical demands of youth soccer match-play (Buchheit, Delhomel, & Ahmaidi, 2008; Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010b; Castagna, Impellizzeri, Cecchini, Rampinini, & Alvarez, 2009). Recovery from previous exercise is also enhanced in young children compared with their older counterparts (Ratel et al., 2006). Furthermore, exercise heart rate and post-exercise heart rate variability, both of which are indicators of fitness/fatigue, have also been reported to be unchanged during a similar competitive period in highly trained young soccer players (Buchheit, Mendez-Villanueva, Quod, & Bourdon, 2010a). This suggests an enhanced ability either to tolerate or delay the onset of cumulative fatigue in this age group.

When physical performance within the next 24–48 h is likely to be impaired as a consequence of insufficient recovery time, any additional recovery intervention that players receive during the post-match period could provide a performance benefit in

Correspondence: M. Buchheit, Physiology Unit, Sports Science Department, ASPIRE, Academy for Sports Excellence, PO Box 22287, Doha, Qatar. E-mail: martin.buchheit@aspire.qa

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the subsequent match (Barnett, 2006; Wilcock, Cronin, & Hing, 2006). Several recovery strategies have been identified and include cryotherapy (cold water immersion, ice pack applications, and cold showers), hydrotherapy (hot water baths, contrast therapy, spa treatment), massage, compression garments, and active recovery (Barnett, 2006). Hydrotherapy has been shown to be an effective recovery intervention and has received growing attention in the literature (Gill, Beaven, & Cook, 2006; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; Rowsell, Coutts, Reaburn, & Hill-Haas, 2009). For example, in elite adult rugby players, contrast water immersion was more effective than passive recovery in speeding up physiological recovery (i.e. serum creatine kinase activity; Gill et al., 2006). Cold water immersion after simulated team sport exercise can offer greater recovery benefits than no recovery treatment on muscle soreness, repeated-sprint ability, and leg strength (Ingram et al., 2009). In young soccer players, cold water immersion alone (Rowsell et al., 2009) or in combination with active recovery (Kinugasa & Kilding, 2009) reduced perceptions of general fatigue and leg soreness after soccer matches more than thermoneutral water immersion (Rowsell et al., 2009) and stretching plus static leg raising (Kinugasa & Kilding, 2009), but did not improve physical test performance. Nevertheless, in these studies (Kinugasa & Kilding, 2009; Rowsell et al., 2009), the effects of the selected interventions on physical test performance were examined without the use of a control condition (i.e. no intervention). Also, to our knowledge, no study has investigated direct effects of post-match recovery strategies on actual (soccer) match running performance, which is likely to be the most important measure of all.

Therefore, to assess the value of post-match recovery strategies in developing soccer players, we examined effects of age on repeated match running performance during two consecutive matches (within 48 h) against the same opponents. We hypothesized that older players would show greater impairment in match running performance, and would therefore be more likely to benefit from post-match recovery strategies. A second aim of this study was to examine the effects of a spa treatment (i.e. a combination of sauna, cold water immersion, and jacuzzi) on match running performance. It was anticipated that impairment would be less after such treatment.

Materials and methods

Participants

Time–motion match analysis data were collected on 104 young football players (from U-13 to U-18 teams) from the same soccer academy for elite-standard players. Stretch stature, sitting height (Harpenden, Baty International, Burgess Hill, UK), and body mass (ADE Electronic Column Scales, Hamburg, Germany) were measured by an experienced tester (Marfell-Jones, Olds, Stewart, & Carter, 2006). The age at peak height velocity (PHV) was used as an indicator of somatic maturity, representing the time of maximum growth in stature during adolescence. Timing of maturity (year) was calculated by subtracting the chronological age (decimal year) at the time of measurement from the age at estimated PHV (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). All the players underwent $\sim$14 h of combined soccer training and competitive play per week. Written informed consent was obtained from the players and their parents. The study conformed to the Declaration of Helsinki and was approved by an institutional ethics committee.

Experimental procedures

Match analyses were performed 1–9 times on each outfield player during a total of 66 international club matches played over a period of 14 months. All matches were performed on 100×70 m standard outdoor natural grass fields with 11 players per side. Tactically, all teams used a 4-4-1-1 formation, a variation of 4-4-2 with one of the strikers playing as a "second striker", slightly behind their partner. Playing time was 2×35 min for U-13 and U-14 players, 2×40 min for U-15, U-16, and U-17 players, and 2×45 for U-18 players. Under-16, U-17, and U-18 players were given spa treatment the morning after Match 1 (i.e. 12–15 h post-match throughout the experimental period). Apart from the spa treatment, all post-Match 1 routines were identical the following day for both treatments (i.e. video analysis feedback followed by a short tactical training session in the afternoon). All players were provided with a post-match nutrition plan developed by a nutritionist to ensure adequate fluid and nutrient intake between matches.

A posteriori, data analysis was divided into two parts. First, within-player changes in match running performance over the two matches were examined separately for each age group without any specific recovery intervention (controls). Second, changes in match running performance between the two matches, as a function of recovery condition, were compared in the U-16, U-17, and U-18 (i.e. post-PHV) players to investigate effects of the spa recovery treatment.

Spa recovery treatment

Spa recovery treatments were a combination of three effective techniques recently proposed by Barnett

(2006). After a 2-min hot shower (33–43°C, temperature self-selected), players performed the following spa sequence three times: sauna (2 min, 85–90°C, seated position), jacuzzi/hydromassage (2 min, 36 ± 1.5°C, seated position with water at the mid-sternal level), followed by a cold bath (2 min, 12 ± 1°C, seated position with water at the iliac crest/umbilicus level). Water temperature for the cold bath was reached and maintained by adding ice when necessary. Players wore shorts during the spa treatment and were encouraged to drink water *ad libitum* to prevent dehydration from the jacuzzi and sauna treatments. At the end of the spa treatment, players were instructed not to shower, just to dry themselves with a towel.

Activity pattern measurements

A global positioning system (GPS) unit capturing data at 1 Hz (SPI Elite, GPSports, Canberra, Australia) was fitted to the upper back of each player using an adjustable neoprene harness. Despite a possible underestimation of high-intensity running distance with a time resolution of 1 Hz (Randers et al., 2010) and in the absence of a "gold standard" method, the current system has been reported to be capable of measuring individual movement patterns in soccer (Randers et al., 2010). More importantly for this study design, the GPS device has been reported to have good reliability [i.e. coefficient of variation of 1.7% (Barbero-Alvarez, Coutts, Granda, Barbero-Alvarez, & Castagna, 2009) and <5% (Coutts & Duffield, 2010)].

Analyses

In total, 1114 player-matches were assessed. Since age and maturity are known to influence the extent and time taken to recover from previous exercise (Ratel et al., 2006), and because maturity differs among players of similar chronological age (Malina, Bouchard, & Bar-Or, 2004), files for players with a PHV age between 0 and +1 year were excluded from analyses so as clearly to separate the two age groups. For the remaining players, we selected time–motion data only for players who met all of the following criteria: (1) played against the same opposition in two consecutive matches within 48 h; (2) played in the same position in both matches; and (3) played the entire match on both occasions. After exclusions, 19 pairs of matches for pre-PHV (<0 year from PHV) players (15 players, –1.0 ± 0.6 year from PHV, age 12.8 ± 0.6 years, height 158 ± 6 cm, body mass 45.2 ± 6.0 kg) and 15 pairs of matches for post-PHV (>+1 year from PHV) players (13 players, 1.5 ± 0.7 years from PHV, age 15.9 ± 1.0 years, height 171 ± 8 cm, body mass 59.0 ± 11.0 kg) were identified for analysis of maturation effects on match running performance. For the recovery intervention analysis, 20 complete player-matches (5 × 2 files for spa treatment and 5 × 2 files for controls) for 5 post-PHV players (+2.0 ± 0.6 years from PVH, age 15.4 ± 0.4 years, height 172.5 ± 7 cm, body mass 64.5 ± 9 kg) were assessed. All match data were analysed with a custom-built Microsoft Excel program to provide objective measures of match running performance. Activity ranges selected for analysis were adapted from previous studies in young soccer players (Buchheit et al., 2008, 2010b; Castagna et al., 2009) as follows: (1) total distance covered, (2) low-intensity running (running speed <13.0 km · h^{-1}), (3) high-intensity running (from 13.1 to 16 km · h^{-1}), (4) very high-intensity running (from 16.1 to 19 km · h^{-1}), and (5) sprinting (>19.1 km · h^{-1}). Very high-intensity activities were calculated as very high-intensity running + sprinting. Repeated-sprint sequences were also examined and were defined as a minimum of two consecutive ≥1-s sprints (>19.1 km · h^{-1}) within 60 s (Bradley et al., 2009). Finally, the highest running speed achieved during the match (peak match speed) was also assessed.

Statistical analyses

Data in the text and tables are presented as means ± standard deviations (±*s*) or ± 90% confidence limits (± 90% CL). Data in Figure 1 are presented with 90% confidence intervals (90% CI). The distribution of each variable was examined with the Kolmogorov-Smirnov normality test. After log-transformation of the data, the changes in match running performance between Match 1 and 2 for each age group, as well as differences in the changes in match running performance after each recovery condition, were expressed as standardized mean differences (Cohen's *d*). The criteria used to interpret the magnitude of Cohen's *d* were: ≤0.2 trivial, >0.2–0.6 small, >0.6–1.2 moderate, >1.2 large (Hopkins, Marshall, Batterham, & Hanin, 2009). In addition, these data were also assessed for practical meaningfulness using an approach based on magnitude of change (Batterham & Hopkins, 2006; Hopkins et al., 2009). We assessed the chances that the true (unknown) changes/differences in match running performance were *greater/beneficial* [i.e. superior to the smallest worthwhile change, SWC (0.2 multiplied by the between-participant standard deviation, based on Cohen's d principle)], *trivial or smaller/harmful*. Quantitative chances of *higher* or *lower* changes were assessed qualitatively as follows: <1%, *almost certainly not*; 1–5%, *very unlikely*; 5–25%, *probably not*; 25–75%, *possible*; 75–95%, *likely*;

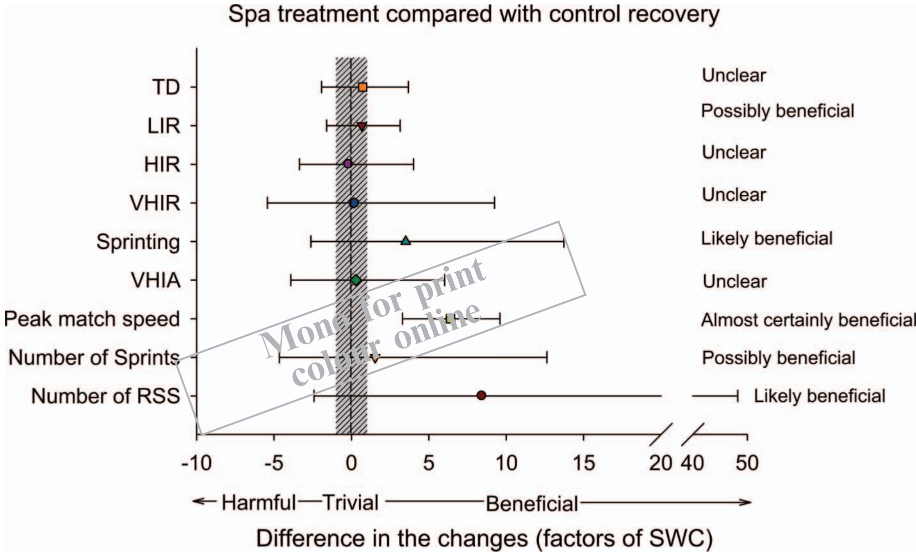

Figure 1. Differences in the changes in match running performance (90% confidence intervals) between two consecutive matches (48 h apart) interspersed or not with a spa treatment (SPA) session. Total distance (TD), low-intensity running (LIR), high-intensity running (HIR), very high-intensity running (VHIR), sprint running (Sprinting), very high-intensity running activities (VHIA), peak speed reached (peak match speed), number of sprints, and number of repeated-sprint sequences (RSS). SWC = smallest worthwhile change.

95–99%, *very likely*; >99%, *almost certain* (Hopkins et al., 2009). If the chance of having *higher* and *lower* differences were both >5%, the true difference was determined to be *unclear*.

Results

Match 2 match running performance was impaired in post-PHV players, whereas it was improved for the pre-PHV players (Table I). Peak match speed, however, was possibly improved during Match 2 in both age groups (Table I). Compared with the control recovery condition, spa treatment had a beneficial impact on low-intensity running, sprinting distance, peak match speed, total number of sprints, and the number of repeated-sprint sequences during Match 2 (Table II and Figure 1).

Discussion

In adult players, physical performance is likely to deteriorate over successive matches without adequate recovery time (Odetoyinbo et al., 2007; Reilly & Ekblom, 2005; Spencer et al., 2005). Recovery strategies such as hydrotherapy can reduce impairments of physical performance and therefore may be beneficial to subsequent match running performance (Barnett, 2006). The necessity and effectiveness of such interventions in developing soccer players is, however, unclear (Rowsell et al., 2009). The main findings of the present study were: (1) without specific post-match recovery interventions, post-PHV players appear to experience some signs of residual fatigue 48 h after the match, as evidenced by a decrease in most match running performance parameters; (2) match running performance is likely improved in pre-PHV soccer players during the following match, even without any post-match recovery intervention; and (3) a combination of sauna, cold water immersion, and jacuzzi (i.e. a spa treatment) the day following a match is likely to reduce the deterioration in match running performance during subsequent matches played within 48 h in post-PHV soccer players.

Effect of age on repeated match running performance

In the present study, only the post-PHV players showed impaired match running performance during the second match compared with the first. This result supports previous findings in adult soccer players showing that a 48-h recovery period is not always sufficient to restore all physical capacities to baseline values (Andersson et al., 2008; Ispirlidis et al., 2008; Odetoyinbo et al., 2007). The decreased number of repeated-sprint sequences observed in the present study is in line with the reduced frequency of repeated-sprint bouts reported across three matches in adult field-hockey players (Spencer et al., 2005), and was consistent with the reduced repeated sprint performance measured using a field test in young soccer players after successive matches (Rowsell et al., 2009). In contrast, sprint-related measures were likely preserved (total number of sprints and total sprint distance) or even improved (peak match speed) in our post-PHV players. This supports the findings of Andersson et al. (2008), who reported that sprint performance returned to baseline values

Table I. Changes in match running performance between two consecutive matches played within 48 h in highly trained pre-PHV and post-PHV soccer players

	Match 1	Match 2	Match 1 vs. Match 2			
			Cohen's *d*	Mean % changes ±90% CL	% Chances Smaller/Trivial/Greater	Outcome
Pre-PHV						
Number of matches	19	19				
TD (m)	6025 ± 1221	5907 ± 1188	−0.1	−2 ± 10	6/94/4	=
LIR (m)	4980 ± 1064	4751 ± 1065	−0.3	−5 ± 11	62/38/0	*Possible* ↓
HIR (m)	584 ± 170	629 ± 140	+0.3	+10 ± 16	3/28/69	*Possible* ↑
VHIR (m)	268 ± 117	329 ± 105	+0.6	+27 ± 22	0/2/98	*Very likely* ↑
Sprinting (m)	193 ± 164	198 ± 112	+0.3	+36 ± 65	6/28/66	*Possible* ↑
VHIA (m)	1045 ± 375	1156 ± 279	+0.4	+14 ± 18	0/13/87	*Likely* ↑
Peak match speed ($km \cdot h^{-1}$)	24.3 ± 1.9	24.5 ± 1.6	+0.1	+1 ± 4	12/53/35	*Possible* ↑
Number of sprints	16 ± 13	16 ± 8	+0.3	+26 ± 50	9/29/62	*Possible* ↑
Number of RSS	6 ± 8	± 5	−0.4	−31 ± 93	68/28/6	*Possible* ↓
Post-PHV						
Number of matches	15	15				
TD (m)	7339 ± 736	6921 ± 1682	−0.2	−6 ± 19	63/37/0	*Possible* ↓
LIR (m)	5706 ± 1209	5365 ± 1030	−0.3	−6 ± 15	76/24/0	*Likely* ↓
HIR (m)	812 ± 341	763 ± 346	−0.1	−7 ± 34	31/68/1	*Possible* ↓
VHIR (m)	437 ± 174	403 ± 178	−0.2	−9 ± 33	56/43/2	*Possible* ↓
Sprinting (m)	384 ± 161	388 ± 188	−0.1	−3 ± 37	9/75/16	=
VHIA (m)	1632 ± 596	1554 ± 572	−0.1	−5 ± 30	28/71/1	*Possible* ↓
Peak match speed ($km \cdot h^{-1}$)	27.3 ± 2.4	27.8 ± 1.9	+0.3	+1.4 ± 4.3	5/37/58	*Possible* ↑
Number of sprints	30 ± 11	31 ± 14	−0.1	−3 ± 33	14/83/4	=
Number of RSS	12 ± 6	10 ± 7	−0.4	−24 ± 50	69/31/0	*Possible* ↓

Note: Values are mean ± *s* for total distance (TD), low-intensity running (LIR), high-intensity running (HIR), very high-intensity running (VHIR), sprint running (sprinting), very high-intensity running activities (VHIA), peak speed reached (peak match speed), number of sprints, and number of repeated-sprint sequences (RSS) observed during the first (Match 1) and second (Match 2) match. Mean percentages of changes are presented with 90% confidence limits (90% CL). All analyses were performed on log-transformed data.

Table II. Changes in match running performance between two consecutive soccer matches played within 48 h with (SPA) or without (control) post-match spa treatment in post-PHV players

	Control		SPA		Changes observed for SPA vs. Control		
	Match 1 (*n* = 5)	Match 2 (*n* = 5)	Match 1 (*n* = 5)	Match 2 (*n* = 5)	Between-condition changes (Cohen's *d*)	Rating	% Chances Beneficial/ Trivial/Detrimental
TD (m)	7191 ± 1438	6768 ± 1405	7802 ± 1377	7570 ± 1598	+0.1	*Trivial*	42/46/13
LIR (m)	5600 ± 884	5361 ± 1040	6176 ± 1104	6024 ± 1026	+0.1	*Trivial*	39/50/10
HIR (m)	732 ± 368	673 ± 357	770 ± 272	746 ± 468	0.0	*Trivial*	27/39/34
VHIR (m)	388 192	327 ± 136	405 ± 110	368 ± 176	0.0	*Trivial*	40/24/37
Sprinting (m)	471 ± 140	406 ± 261	451 ± 188	450 ± 156	+0.6	*Moderate*	75/15/10
VHIA (m)	1591 ± 620	1406 ± 429	1626 ± 490	1547 ± 728	+0.1	*Trivial*	38/31/30
Peak match speed ($km \cdot h^{-1}$)	29.7 ± 0.9	28.6 ± 1.7	29.1 ± 1.7	29.7 ± 1.1	+1.3	*Large*	99/1/0
Number of Sprints	35 ± 11	31 ± 17	34 ± 13	31 ± 13	+0.3	*Small*	55/20/25
Number of RSS	16 ± 7	9 ± 9	12 ± 8	11 ± 8	+1.0	*Moderate*	83/8/9

Note: SPA and Control stand for the implementation or not respectively of a spa treatment the day flowing the first match (Match 1). Match 2 is the second match. Values are mean ± *s* for total distance (TD), low-intensity running (LIR), high-intensity running (HIR), very high-intensity running (VHIR), sprint running (sprinting), very high-intensity running activities (VHIA), peak speed reached (peak match speed), number of sprints, and number of repeated-sprint sequences (RSS). All analyses were performed on log-transformed data.

within 5 h after a match in elite-standard female soccer players. However, these findings are in contrast with the decreased maximal sprint performances reported within 24–72 h after a soccer match in elite-standard male adult (Ispirlidis et al., 2008) and well-trained young (Rowsell et al., 2009) players. These contrasting results could be related to the younger age of our players compared with those of

Ispirlidis et al. (2008) (21 years vs. 14–17 years) and the nature of the measurements: field test (Rowsell et al., 2009) vs. actual match performance (present study). It is also worth noting that changes in match running performance had high inter-individual variations (as inferred from the large confidence intervals; Table I), suggesting heterogeneous match-induced fatigue. Differences in player characteristics (e.g. physical capabilities, training background), as well as position-specific differences in match demands (Buchheit et al., 2010b; Stroyer, Hansen, & Klausen, 2004), could also contribute to these individual responses. Nevertheless, the present findings are in line with previous work reporting post-match fatigue-induced decrements in some physical performance characteristics in highly trained young soccer players (Rowsell et al., 2009). These players are therefore likely to benefit from post-match recovery strategies. It should however be acknowledged that possible differences in maturity status between our players and those from the opposing teams could have resulted in different recovery abilities and hence altered the nature of play in the second match. Similarly, the outcome of the first match, which could have affected player motivation, was not taken into account in the analyses and is therefore a potential limitation of this study.

The present study does not allow detailed investigation of possible mechanisms that account for the changes in match running performance seen during the second match in the post-PHV players. Future studies might explore changes in blood/muscle and fatigue makers such as plasma creatine kinase concentration (Gill et al., 2006) and subjective feelings of recovery or muscle soreness (Rowsell et al., 2009; Vaile, Gill, & Blazevich, 2007). Nevertheless, while most of the body's systems (i.e. metabolic, musculoskeletal, endocrine, immune, and nervous systems) are highly stressed during soccer matches (Andersson et al., 2008; Ispirlidis et al., 2008), the present data confirm differences in recovery patterns of various physiological responses in response to match-play (Andersson et al., 2008; Ispirlidis et al., 2008). The increase in peak match speed could be related to short-term supercompensation (Viru, 1984), since characteristics of speed recover within a few hours after matches (Andersson et al., 2008). In contrast, since we did not assess whether the rehydration and nutrition strategies applied in this study were effective at fully restoring fluids and energy stores (Jentjens & Jeukendrup, 2003), an incomplete "metabolic" recovery cannot be excluded. Factors such as glycogen availability and muscle buffering capacity are known to influence high-intensity running speeds during matches (Balsom, Wood, Olsson, & Ekblom, 1999).

In the pre-PHV players, meaningful improvements in match running performance occurred during the second match (Table I). Physical performance is known to be dependent on the balance between physical capability and training- and/or exercise-induced fatigue (Viru, 1984). Therefore, the increased physical capabilities noted in the second match could be related to faster post-exercise recovery abilities in pre-PHV athletes (Ratel et al., 2006). This could be related to their lower muscle mass and force production ability that is accompanied by less homeostatic disturbance and less muscle damage. The latter can occur in highly trained athletes, as was the case for the present players. Alternatively, short-term improvements in physical performance (i.e. supercompensation; Viru, 1984) could be another explanation. For example, cardiovascular function can improve as early as 48 h after high-intensity intermittent exercise, as evidenced by decreased exercise heart rates for given submaximal running speeds (Buchheit, Laursen, Al Haddad, & Ahmaidi, 2009). However, irrespective of the mechanisms involved, the present results show that pre-PHV players are unlikely to experience marked fatigue during two consecutive matches performed within 48 h. While acknowledging that without the spa treatment in this age group definitive conclusions cannot be drawn, our findings indicate that the implementation of post-match recovery strategies in pre-PHV players is not necessary. The present findings also suggest that repeated-match sequences could be used by coaches as specific training strategies to improve match running performance in pre-PHV soccer players. Investigations of physiological effects and associated changes in physical performance after consecutive match sequences/training practices over longer durations in young developing players are therefore warranted.

Effect of spa recovery treatment on repeated match running performance

In the present study, post-PHV players experienced smaller decrements in repeated-match running performance after a combination of sauna, cold water immersion, and jacuzzi (i.e. spa treatment) than the no-recovery-intervention controls. To our knowledge, no study has assessed the effect of any post-match recovery strategy on actual soccer match running performance. In young soccer players, cold water immersion alone (Rowsell et al., 2009) or in combination with active recovery (Kinugasa & Kilding, 2009) was shown to reduce the perception of general fatigue and leg soreness after soccer matches more than thermoneutral water immersion (Rowsell et al., 2009) and stretching and static legs raising (Kinugasa & Kilding, 2009), but failed to improve physical test performance. Comparison with these studies conducted in players of similar ages suggests that spa treatment is more effective than the other two recovery interventions, and/or that match running performance is a more sensitive indicator of required physical ability than performance in simple field tests. The inter-individual differences in the responses to spa treatment (Table II and Figure 1) also suggest that not all players benefit from post-match recovery interventions to the same extent. As previously hypothesized, individual and/or positional differences in match-related fatigue could account for these observations. However, while the present investigation provides support for the use of post-match recovery strategies to promote restoration of physical capabilities, precise physiological mechanisms by which match running performance (i.e. sprinting) was possibly improved after spa treatment remain unclear.

The present results also suggest that a combination of sauna, cold water immersion, and jacuzzi was effective in improving neuromuscular function, since sprint-related measures improved more than those in the controls. Nevertheless, peak match speed was improved during the second match in both age groups, even without any recovery intervention. It is therefore more likely that spa treatment was particularly effective at improving the ability either to sprint longer or to repeat sprints (leading to a greater total sprinting distance and a greater number of sprints and repeated-sprint sequences). Potential mechanisms that explain these improvements cannot be identified here, but since rehydration and nutrition strategies were similar for both conditions and that the spa treatment is unlikely to have affected metabolic factors possibly related to the ability to repeat sprints (e.g. repletion of glycogen stores; Balsom et al., 1999), an improved psychological perception of well-being (Marcora, Staiano, & Manning, 2009) could have occurred. Although we do not have data on ratings of perceived exertion to support this, the widely reported improved perceived recovery (i.e. lower perception of general fatigue and leg soreness) following post-exercise recovery treatments (Parouty et al., 2010; Rowsell et al., 2009) could have also predisposed players to engage in more high-intensity exercise during the second match (Walton, Kennerley, Bannerman, Phillips, & Rushworth, 2006). Players generally also perform better when they believe that they have received beneficial treatment (i.e. placebo effect; Beedie & Foad, 2009). Sauna and jacuzzi interventions, which promote vasodilatation, are also thought to increase antioxidant and antibody supply, improving feelings of well-being (Prentice, 1999). Cryotherapy can reduce cell necrosis, oedema, and neutrophil migration, as well as slow cell metabolism and nerve conduction velocity, which in turn reduce muscle soreness (Wilcock et al., 2006). It is also possible that the repeated alternations of thermotherapy (sauna and jacuzzi, inducing vasodilatation) and cryotherapy (cold water immersion, inducing vasoconstriction), as well as alternations in hydrostatic pressure (sauna vs. both immersion conditions), resulted in a muscle "pumping effect". Associated changes in intra-muscular pressure and muscle blood flow could have facilitated the reduction of post-match inflammatory responses and muscle soreness (Vaile et al., 2007). Overall, these mechanisms could have improved subjective feelings of recovery after the first match attributable to the spa treatment (Rowsell et al., 2009). Therefore, the present results suggest that spa treatment is an effective strategy to enhance recovery of match performance over successive soccer matches, since better performing players generally undertake more high-intensity running during matches (Mohr, Krustrup, & Bangsbo, 2003). Whether the beneficial effect of a spa treatment on match running performance influences match outcomes (i.e. winning or losing) is not clear because match running performance is only one of several important factors for success in soccer.

In conclusion, we found that only post-PHV players experience match-induced fatigue within 48 h, as evidenced by a decreased match running performance during the following match. In contrast, improved match running performance was more likely in pre-PHV players, suggesting that the implementation of post-match recovery strategies in this age group is not necessary. However, in post-PHV players, a combination of sauna, cold water immersion, and jacuzzi (i.e. spa treatment) the day after a match is likely to limit the deterioration in match running performance (especially sprinting) in the following match. Assessment of player/position-related fatigue, as well as individual responses to recovery treatment are required to improve the individualization of training and competition schedules in developing soccer players.

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