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Physiological and performance adaptations to an in-season soccer camp in the heat: Associations with heart rate and heart rate variability

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The aim of the present study was to examine the associations between adaptive responses to an in-season soccer training camp in the heat and changes in submaximal exercising heart rate (HRex, 5-min run at 9 km/h), postexercise HR recovery (HRR) and HR variability (HRV). Fifteen well-trained but non-heat-acclimatized male adult players performed a training week in Qatar (34.6 ± 1.9°C wet bulb globe temperature). HRex, HRR, HRV (i.e. the standard deviation of instantaneous beat-to-beat R–R interval variability measured from Poincaré plots SD1, a vagal-related index), creatine kinase (CK) activity, plasma volume (PV) changes, and post-5-min run rate of perceived exertion (RPE) were collected at six occasions in temperate environmental conditions (22°C). Players also performed the yo-yo intermittent recovery test level 1 (Yo-Yo IR1) in the same environmental conditions (22°C), both at the beginning and at the end of the training week. Throughout the intervention, HRex and HRV showed decreasing (*$P < 0.001$*) and increasing (*$P < 0.001$*) trends, respectively, while HRR remained unaffected (*$P = 0.84$*). Changes in HRex [–0.52, 90% confidence limits (–0.64; –0.38), *$P < 0.001$*] and SD1 [0.35 (0.19; 0.49), *$P < 0.001$*] were correlated with those in PV. There was no change in RPE (*$P = 0.92$*), while CK varied according to training contents (*$P < 0.001$*), without association with HR-derived measures. Yo-Yo IR1 performance increased by 7 ± 9% (*$P = 0.009$*), which was correlated with changes in HRex [–0.64 (–0.84; –0.28), *$P = 0.01$*]. In conclusion, we found that an in-season soccer training camp in the heat can significantly improve PV and soccer-specific physical performance; both of which are associated with changes in HRex during a 5-min submaximal run.

Soccer matches are often played in challenging conditions where the temperature can exceed 30°C, with or without a high relative humidity. With the recent announcement of the 2022 soccer World cup to be held in Qatar, there is likely to be an increased interest in methods for improving training and soccer performance in the heat. While the literature on actual match (running) performance is not extensive, players competing in hot conditions generally cover less distance and show exacerbated match-related fatigue than under cooler conditions (Mohr et al., 2010; Ozgunen et al., 2010).

Experimental studies have shown that, in addition to the various interventions that can prevent excessive dehydration and/or increase in core temperature (e.g. precooling, ice pack applications, and ice-slush ingestion; for review, see Quod et al., 2006; Maughan et al., 2010), exercise-heat acclimation is likely the most effective strategy to limit the reduction in match running performance in hot conditions (Sunderland et al., 2008). As such, training in the heat for a few days/weeks prior to soccer competitions in hot environments is highly recommended (Grantham et al., 2010; Maughan et al., 2010). The physiological adjustments to heat acclimation are well established (e.g. Ladell, 1951; Hellon et al., 1956) and include decreased central temperature, reduction of the temperature threshold for sweating (Ladell, 1951), plasma volume (PV) expansion, enhanced myocardial efficiency and improved cardiovascular adjustments (Wyndham et al., 1976), reduced oxygen uptake at a given power output, and muscle glycogen sparing (Young et al., 1985). Therefore, it is reasonable to postulate that exercise-heat acclimation can have an ergogenic effect, even in temperate conditions (i.e. 22°C). While this has recently been demonstrated in well-trained cyclists (Lorenzo et al., 2010), it is still unknown if training in the heat has ergogenic benefit for soccer players when playing in temperate conditions. If this was to be effective, training in the heat could also be recommended as a specific training intervention to improve players' aerobic fitness level before or during the competitive season.

To monitor players' adaptation to training and to assess possible changes in fatigue and/or fitness level, several methods/tools are currently implemented in the field. These include the regular tracking of hematological/endocrine variables and perceptual fatigue responses (for review, see Hooper & Mackinnon, 1995; Borresen & Lambert, 2009), and more recently, the monitoring of heart rate (HR), HR recovery (HRR), and HR variability (HRV) during and after a submaximal running test in the field (i.e. 5 min of submaximal running followed by 5 min of seated recovery, 5′-5′ test; Buchheit et al., 2008, 2010a). The advantage of the latter method is that it is noninvasive and does not require a player's subjective assessment, which can be biased to influence selection in the team. Additionally, the 5′-5′ test is a relatively non-fatiguing test, and it can easily be incorporated into a training schedule in professional field-based team sports such as soccer. Finally, cardiac autonomic activity as inferred from HRV measures is likely to play an important role in the training response (Hautala et al., 2009) and may provide information regarding the functional adaptations occurring to a given training stimulus at the individual level. For example, changes in HR-derived indices were largely correlated with changes in repeated-sprint ability in highly trained handball players (Buchheit et al., 2008) and maximal aerobic speed and 10-km running performance in recreational distance runners (Buchheit et al., 2010a). However, there is currently no comparable data in soccer, and it is unknown if the adaptive responses to training (in the heat) can also be assessed with these HR measures. Because exercise HR (HRex; Convertino, 1991) and HRV (Buchheit et al., 2009) are decreased and increased by acute PV expansion, respectively, it is possible that exercise in the heat-induced changes in PV could be tracked via changes in these HR measures.

Therefore, to examine (1) the possible ergogenic effect of a typical competitive week in a hot environment on physical performance in temperate conditions and (2) whether adaptive (i.e. physiological, perceptual fatigue, and exercise performance) responses to exercise-heat acclimation are associated with changes in HR-derived measures, we monitored changes in submaximal exercise HR, HRR, HRV, rate of perceived exertion (RPE), plasma creatine kinase (CK) activity, PV, and soccer-specific physical performance in a group of well-trained soccer players during and after an in-season training week in hot conditions.

Materials and methods

Participants

From an initial sample of 20 competitive (belonging to a Faroe Island first division team and a Danish second division team) male soccer players who participated in this study, five players missed at least one training/testing session and/or did not perform the post-intervention physical performance test. Therefore, 15 players were considered for analysis (age 26.2 ± 5 years, height 183 ± 6 cm, and body mass 79.6 ± 7.3 kg). The study was approved by the local research ethics committee, conformed to the recommendations of the Declaration of Helsinki, and players provided their informed consent. Only outfield players were included in the present study.

Experimental overview

The study was conducted during an in-season 11-day training camp in the Middle East (Qatar – October 2010). This training camp was completed 3–4 months following the preparatory training phase of the soccer season. In their respective clubs, players trained 5–6 times a week and had at least one competitive game per week. Because this camp was designed to reproduce a typical in-season (training) week (Table 1), a competitive game was played on each weekend (while only friendly games could be organized in the present study, playing positions were unchanged, and all players played during the entire game, i.e. 90 min). During the first 3 days of the camp, players trained and played indoor (controlled environmental conditions, Table 1) on a synthetic turf (Classic series, G3, Mondo, Italia). Then, they trained and played outside (Table 1) on a synthetic turf (Classic series, G1) from the 4th to the 10th day (Fig. 1).

To assess the effect of the in-season training in the heat on soccer-specific physical performance in temperate conditions, players performed the yo-yo intermittent recovery test level 1 (Yo-Yo IR1; Krustrup et al., 2003) on the indoor field at the start (5th day) and immediately after (11th day) the experimental week. The Yo-Yo IR1 was preferred to match-related measures because playing position affects match running performance (Di Salvo et al., 2007). Briefly, the Yo-Yo IR1 consists in repeating 20-m shuttle runs at increasing velocities (starting at 10 km/h), with 10 s of active recovery (consisting of 5 m of jogging) between runs until exhaustion (Krustrup et al., 2003). The Yo-Yo IR1 was performed 48 h after each game. This timing is similar to that adopted by some professional European clubs that compete on a weekly basis, that is, whereby they commonly perform high-intensity aerobic training 48–72 h postgame. Players were familiarized with this test prior to the commencement of the study.

As a component of the warm-up of the morning training sessions (starting ~10h30) on the 3rd, 4th, 5th, 9th, 10th, and 11th day, players performed a standardized 5-min submaximal run (i.e. 9 km/h) on the indoor football field, followed by 5 min of seated recovery (5′-5′ test; Buchheit et al., 2010a, 2010b), where beat-to-beat HR (Polar Team system 2, Polar Electro, Kempele, Finland) and RPE (Borg CR-10 scale) were monitored. HR was also monitored during all training sessions, including the Yo-Yo IR1. Additionally, venous blood samples were collected every morning after breakfast to follow changes in plasma CK activity and PV as a result of the training intervention and heat exposure. Finally, training load was estimated for all players via calculation of training impulses (TRIMPs; using training time and associated mean HR; Impellizzeri et al., 2004). Players could drink *ad libitum* during all training sessions and were provided with a post-training nutrition plan developed by a nutritionist to ensure adequate fluid and nutrient intake between the sessions.

5′-5′

The 5′-5′ test was always performed indoor under controlled environmental conditions (as detailed in Table 1), that is, during the heat exposure period, players first completed the 5′-5′ test inside and then trained outside. Each player was familiarized with the running test and HR recording procedures prior to commencement of the investigation. For convenience, all players were tested simultaneously with the intensity of the 5-min submaximal exercise bout fixed at 9 km/h (Buchheit et al., 2010b). At the end of the exercise, players stopped their effort within 3 s and immediately

Table 1. Training contents and environmental variables during the entire training camp

Day	1	2	3	4	5		6	7	8	9	10	11
Training location	Inside	Inside	Inside	Outside	Inside	Outside	Outside	Outside	Outside	Outside	Outside	Inside
Activity	Training (skills)	Training (tactics)	Friendly game	Training (recovery/ skills)	Yo-Yo IR1	Walking	Training (skills + tactics)	Training (skills + tactics)	Training (skills + tactics)	Friendly game	Training (recovery /skills)	Yo-Yo IR1
Duration (min)	47	75	94 ± 3	60	19 ± 3	60	93	70	72	95 ± 3	60	19 ± 3
Intensity (% HRmax)	70 ± 10	63 ± 12	84 ± 4	50 ± 5	90 ± 3	N/A	68 ± 6	70 ± 7	65 ± 7	83 ± 4	51 ± 5	89 ± 3
TRIMP (AU)	84 ± 24	107 ± 34	256 ± 35	52 ± 9	66 ± 10	N/A	154 ± 30	124 ± 27	100 ± 27	250 ± 30	52 ± 10	64 ± 10
Wet temp. (°C)	17.4	†	†	N/A	†	N/A	27.5	28.2	29.5	26.3	26	†
Dry temp. (°C)	20.6						39.8	39.6	41.2	42.6	38.7	
Globe temp. (°C)	22.2						52.8	49.7	55.7	54.4	46.6	
WBGT (°C)	18.8			37*		36*	35.1	34.6	36.6	34.9	32.1	
RH (%)	55			N/A		N/A	24	30	26	12	27	
Flow (m/s)	0.4						0.3	0.3	0.3	0.3	0.3	

Values are means ± standard deviation.

*Values estimated based on http://www.wunderground.com/history/airport/OTBD/2010/10/8/WeeklyHistory.html.

†Not measured. However, due to the controlled indoor environment, it was assumed that these values were similar to day 1. Gray cells refer to activities performed in hot environment.

AU, arbitrary units; HRmax, maximal heart rate; N/A, not available; RH, relative humidity; temp., temperature; TRIMP, training impulse; WBGT, wet bulb globe temperature.

sat on the grass for 5 min, avoiding any movement. Because this study was conducted in the field, and based on previous findings (Bloomfield et al., 2001), respiratory rate was not controlled. Additionally, the time-domain HRV index used (see below) is not significantly affected by changes in the breathing rate, being suitable for the measurement of cardiac vagal outflow during 'free-running' ambulatory conditions (Penttila et al., 2001).

HR data analysis

All R–R series data were extracted with dedicated software (Polar Team system 2 software 1.3.0.4, Polar Electro). Occasional ectopic beats were automatically replaced with interpolated adjacent R–R interval values. Mean HR during the last 30 s of the 5′-5′ exercise period was computed and termed HRex. Postexercise HRR was calculated by taking the absolute difference between the HRex and the HR recorded after 60 s of recovery (Buchheit et al., 2010b). The standard deviation (SD) of instantaneous beat-to-beat R–R interval variability measured from Poincaré plots (SD1; Huikuri et al., 1996) was calculated during the last 3 min of the 5-min recovery period following the 5-min submaximal exercise test (Buchheit et al., 2010b) as a vagal-related HRV index (Tulppo et al., 1996). This index is related to cardiac parasympathetic activity and highly correlated ($r = 0.98$; Penttila et al., 2001) with the square root of the mean of the sum of the squares of differences between adjacent normal R–R intervals (rMSSD), which was used previously with the 5′-5′ test (Buchheit et al., 2010b). The analysis was computed with the accompanying Polar software, which has shown to provide accurate measurements (Nunan et al., 2009). Day-to-day variations in HRex, HRR, and HRV during a competitive period in soccer players are on average 3.4%, 13.3%, and 10.7%, respectively (Buchheit et al., 2010b). The highest HR reached during each Yo-Yo IR1 (5-s average) were retained as maximal HR at the beginning and end of the training week.

Blood collection

Venous blood was drawn in a sitting position at the same time of the day (i.e. 09:00–10:00 a.m.), according to standard procedures. For the blood sampling material, Becton Dickinson (Franklin Lakes, New Jersey, USA) ethylenediaminetetraacetic acid vacutainers were used.

Blood analysis

Blood was analyzed in-between 1 h on a Sysmex XT2000i (Sysmex, Norderstedt, Germany) to obtain hematological data like hemoglobin (Hb) and hematocrit (Hct). The coefficient of variations (CV; %) for repeated measures on the same day were 0.3% for Hb and 0.4% for Hct, respectively. PV changes were calculated from the hematology data we obtained from the Sysmex XT2000i using the formula previously described by Van Beaumont (1972). The CV for inter-day changes in PV estimated with the same formula has been reported to be 18% (Weinstein et al., 1998). The samples were then centrifuged, and the plasma fraction analysis was performed using a Roche Cobas Integra 400 plus (Roche Diagnostics, Mannheim, Germany). The CV for CK was 1.0 for human sera in a range of 157–652 U/L for the Cobas Integra. The evaluated parameters were all validated by the controls provided by Sysmex and Roche.

Statistical analyses

Data are presented as means (± SD) and correlations as means (90% confidence limits). The distribution of each variable was examined with the Kolmogorov–Smirnov

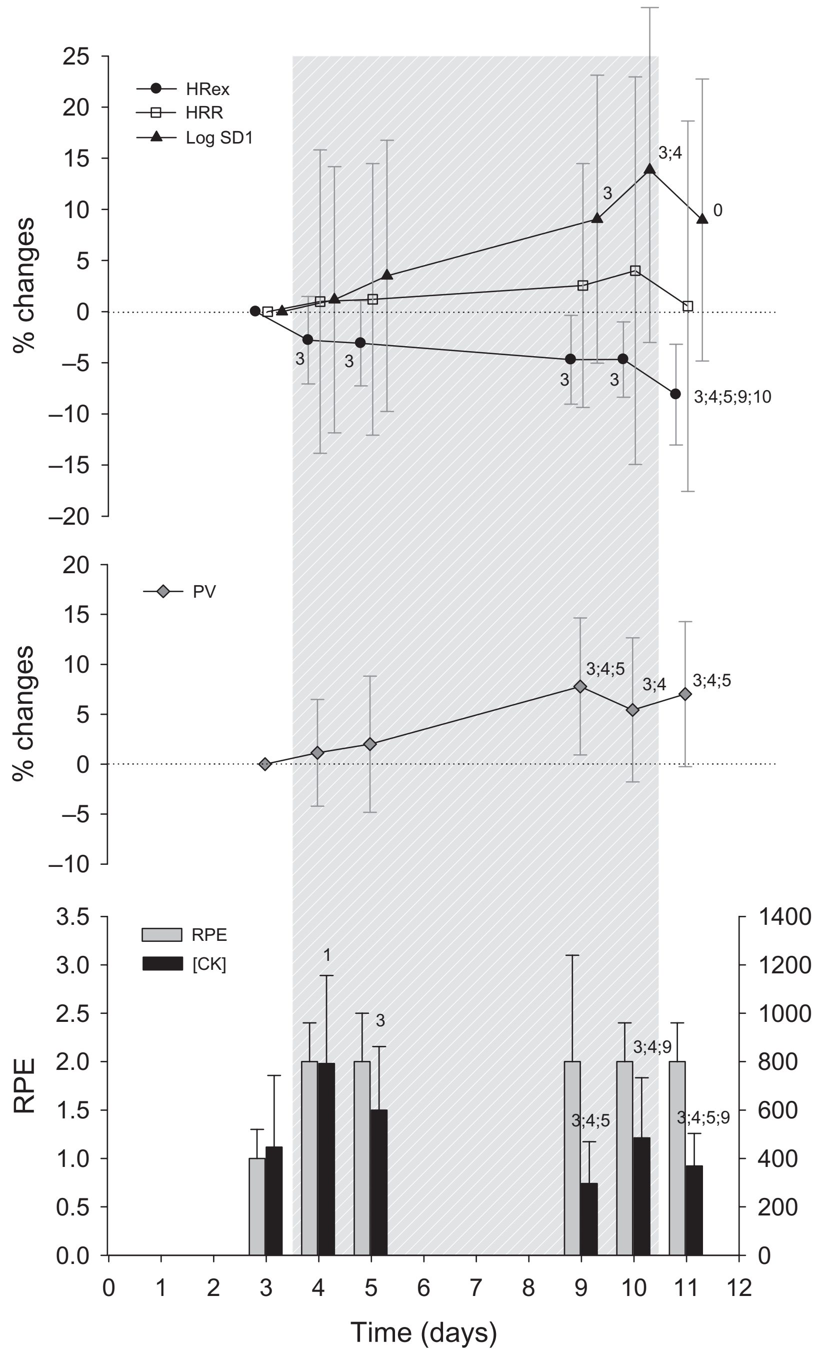

Fig. 1. Changes in heart rate (HR) during the 5-min submaximal run [exercise HR (HRex)], postexercise HR recovery (HRR) and HR variability (i.e. logarithm of the standard deviation of instantaneous beat-to-beat R–R interval variability, log SD1, measured from Poincaré plots during the last 3 min of recovery following exercise; upper panel). Estimated changes in plasma volume (PV; middle panel) and post-5′-5′ rate of perceived exertion (RPE) and plasma creatine kinase (CK) activity (bottom panel). Values are mean ± SD for the 15 players with complete data set for the six HR recordings. Gray areas represent heat exposure. Numbers refer to significant difference ($P < 0.05$) vs the given day.

normality test. When data were skewed or heteroscedastic (i.e. SD1 and CK), data were transformed by taking the natural logarithm to allow parametric statistical comparisons that assume a normal distribution. For comparison with the literature, CK values are nevertheless presented as non-transformed. Changes in HR-derived indices and blood variables as a result of training in the heat were analyzed using a one-way analysis of variance for repeated measures (*time, 6 levels*). Because acute muscle damage or accumulated fatigue related to the previous training days (and game) can affect running performance independently of cardiorespiratory fitness, pre- vs post-training performances at the Yo-Yo IR1 were compared with a one-way analysis of covariance

(ANCOVA) for repeated measures (*pre vs post*), with (1) CK values of the testing day or (2) cumulated TRIMPs over the two previous training days used as a co-variables. When a significant main effect was found, Bonferoni's post-hoc tests were performed. Pre- vs post-training maximal HR during the Yo-Yo IR1 were compared with a paired (two-tailed) t-test. Pearson's product-moment correlation analysis was also used to assess the relationship between changes in HR-derived indices, blood variables, and Yo-Yo IR1 performance. Each of these analyses was carried out with Minitab 14.1 Software (Minitab Inc., Paris, France), and the level of significance was set at $P \leq 0.05$. In addition to measures of statistical significance, the following criteria were adopted to interpret the magnitude of the correlation (r) between test measures: <0.1 = trivial; 0.1–0.3 = small; >0.3–0.5 = moderate; >0.5–0.7 = large; >0.7–0.9 = very large; and >0.9–1.0 = almost perfect. If the 90% confidence limits overlapped positive and negative values, the magnitude was deemed to be unclear; otherwise, that magnitude was deemed to be the observed magnitude (Hopkins et al., 2009).

Results

Local temperature and training/competitive load

As shown in Table 1, mean environmental temperature was stable throughout the experimental period, with mean midday values (time of training) of 39.8 ± 1.0°C for dry temperature, 27 ± 2% for relative humidity, and 34.6 ± 1.9 for wet bulb globe temperature. Players received similar playing times during the two friendly games, and there was no differences in game TRIMPs for the players included in the present analysis ($P = 0.31$).

Changes in HR-derived indices and RPE during the 5′-5′ test during a training week in the heat

On day 3, mean HRex during the 5′-5′ test was 135 ± 15 beats/min (71 ± 6% maximal HR), HRR 48 ± 7 beats/min, and postexercise log SD1 1.3 ± 0.2 ms (non-transformed SD1 = 21.4 ± 14.6 ms). As shown in Fig. 1, HRex decreased throughout the experimental days (main *day* effect, $P < 0.001$). Conversely, log SD1 increased (main *day* effect, $P < 0.001$). As illustrated in Fig. 1, there was, however, no significant change in either HRR (main *day* effect, $P = 0.84$) or post-5′-5′ RPE (main *day* effect, $P = 0.92$).

Changes in estimated PV and CK during a training week in the heat

As shown in Fig. 1, estimated PV increased throughout the study (main *day* effect, $P < 0.001$), while plasma CK showed significant fluctuations ($P < 0.001$).

Changes in Yo-Yo IR1 performance after a training week in the heat

Maximal HR at the end of the Yo-Yo IR1 decreased after the training intervention (188 ± 10 vs 187 ± 10, $P = 0.02$). Mean running distance increased after training in the heat by 7 ± 9% (range from −5.6% to +27.2%), from 2380 ± 334 m to 2527 ± 321 m ($P = 0.009$). After adjustment on plasma CK values, the difference was still significant ($P = 0.033$), with estimated least squares means (LSM) of 2394 ± 333 m and 2513 ± 327 m for pre- vs post-training, respectively. Similarly, adjustment on cumulated TRIMPs over the two previous days did not change the results (with LSM of 2388 ± 338 m and 2519 ± 322 m for pre- vs post-training, respectively, $P = 0.019$).

Relationship between HR-derived indices, CK, PV and Yo-Yo IR1 performance

Individual responses in HRex and log SD1 were significantly correlated with these in PV [–0.52 (–0.64; –0.38), $P < 0.001$ and 0.35 (0.19; 0.49), $P < 0.001$ for HRex and log SD1, respectively]. We also found a large correlation between absolute changes in HRex and Yo-Yo IR1 performance (Fig. 2(a)). No other significant correlations were found.

Discussion

In this study, we report for the first time the time course of submaximal HRex, HRR, postexercise HRV, RPE, plasma CK, and PV in well-trained soccer players during an in-season training week in the heat. Our main results were as follow: (1) throughout the intervention, HRex and HRV during/after the 5′-5′ test showed decreasing and increasing trends, respectively, while HRR remained unaffected; (2) the changes in HRex during the 5′-5′ test and post-5′-5′ HRV were moderately-to-largely related to these in PV, while there was no relation with plasma CK or RPE; and (3) average performance at the Yo-Yo IR1 was improved by 7% after the training week, which was largely associated with changes in HRex.

To monitor players' adaptation to training and to assess possible changes in fatigue and/or fitness level, coaches and their staff are generally looking for objective, noninvasive, time-efficient, and on-field tools. Because the 5′-5′ test is a relatively non-fatiguing test that can easily be incorporated into a training schedule in professional field-based team sports such as soccer (Buchheit et al., 2010b), we investigated whether HR-derived measured during and after the test could be useful to monitor the adaptive responses to a training week in the heat in well-trained soccer players. Throughout the training intervention, group average HRex during the 5′-5′ test and postexercise HRV showed decreasing and increasing trends, respectively, while HRR remained

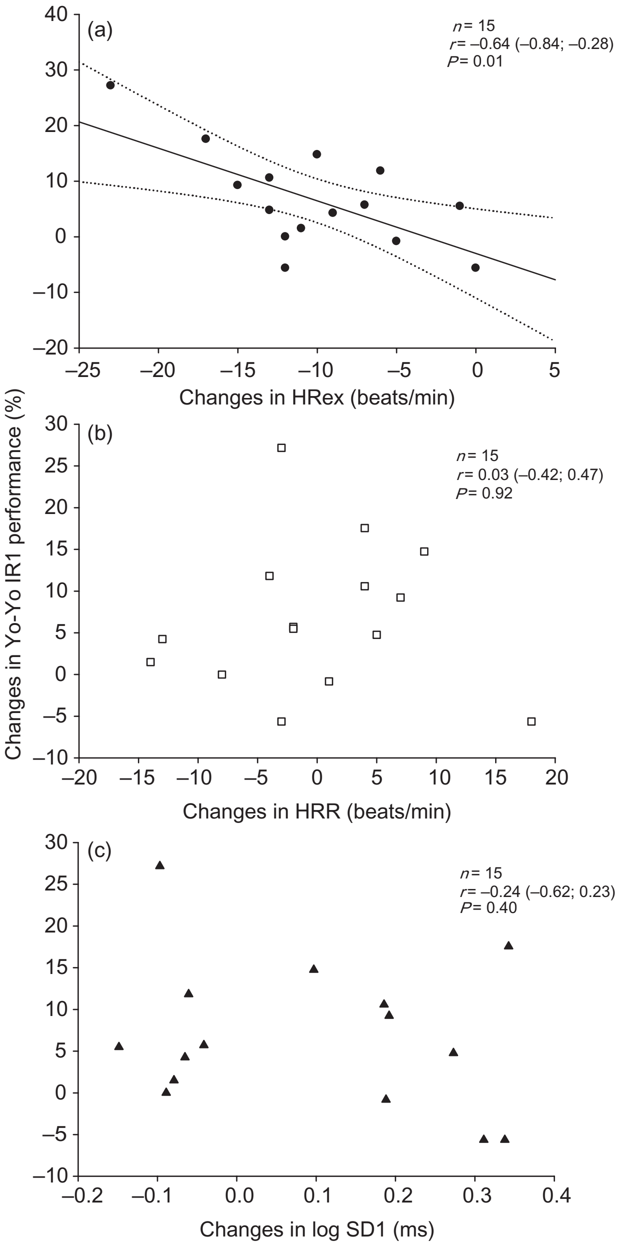

Fig. 2. Relationships between the change in performance at the yo-yo intermittent recovery test level 1 (Yo-Yo IR1) and the changes in heart rate during the 5-min submaximal run [exercise heart rate (HRex), (a)], postexercise heart rate recovery [HRR, (b)] and heart rate variability, that is, the logarithm of the standard deviation of instantaneous beat-to-beat R–R interval variability measured from Poincaré plots during the last 3 min of recovery following exercise [log SD1, (c)] after the in-season training week in the heat.

unaffected (Fig. 1). While the lack of a control group is a major limitation of the present study, the magnitude of changes observed in the HR measures derived from the 5′-5′ test suggest that the intervention was meaningful.

The changes observed in the HR-derived indices during and after the 5′-5′ test (e.g. –8% and +9% for HRex and postexercise HRV, respectively) were substantially greater than (HRex) or at least similar to (HRV) the day-to-day variations generally observed [from 2% (Lamberts et al., 2004) to 3% (Buchheit et al., 2010b) for HRex and 10% for postexercise HRV (Buchheit et al., 2010b)]. More importantly, the changes were comparable (Buchheit et al., 2008, 2010a) or even greater than (Buchheit et al., 2010b) the changes previously observed after training interventions much longer than in the present study. Indeed, there was no change in these HR measures in highly trained young soccer players who trained and competed for 3 weeks in moderate temperature conditions (i.e. 22.3°C) (Buchheit et al., 2010b). In another study on highly trained young handball players, a 2-month high-intensity training intervention (for a total of 16 sessions) resulted in a 5% decrease in HRex and 10–20% increases in HRR and postexercise HRV (Buchheit et al., 2008). The mechanisms underlying training-induced changes in HRex, HRR, and postexercise HRV are diverse and complex. Although all vagally mediated, HRex, HRR, and postexercise HRV have been suggested to (1) represent independent aspects of cardiac parasympathetic function (Buchheit et al., 2007b) and (2) respond differentially to endurance training (Yamamoto et al., 2001; Buchheit et al., 2008, 2010a). In addition to improvements in cardiorespiratory fitness, which directly determine relative exercise intensity and energy systems contribution and, in turn, metaboreflex stimulation (with the greater the anaerobic participation, the slower HRR and the poorer postexercise HRV; Buchheit et al., 2007a), exercise-induced changes in PV have also been proposed to explain changes in HRex (Convertino, 1991), HRR, and HRV after training (Buchheit et al., 2009).

An enlarged stroke volume (Convertino, 1991) and an increased baroreflex-mediated parasympathetic activity (Spinelli et al., 1999) are suggested to account for the changes in HRV observed within 24–48 h after exercise (Al Haddad et al., 2009; Buchheit et al., 2009). In agreement with previous observations (Buchheit et al., 2009), we observed moderate correlations between individual changes in both 5′-5′ HRex and postexercise HRV and PV (–0.52 and 0.35 for HRex and HRV, respectively). Playing football in the heat is well-known to exacerbate fluid loss and dehydration (Mustafa & Mahmoud, 1979), which can, in turn, trigger PV expansion (Wyndham et al., 1976; Convertino, 1991). In fact, the present results showed that in no more than 7 days of soccer training/playing in the heat (Table 1), players presented a significant 7% increase in PV (Fig. 1). While we acknowledge that the variability of these PV changes is large (e.g. CV = 18%; Weinstein et al., 1998), the changes observed in the present study were significant and displayed consistent increase from day to day (Fig. 1).

The lack of changes in HRR throughout the intervention (Fig. 2) could be related to the relatively low running speed during the 5′-5′ test (i.e. 9 km/h) for these well-trained players, which was likely associated with very low levels of system stress metabolite accumulation in the blood (e.g. lactate or epinephrine). Metaboreflex stimulation was therefore likely very low at the start of the training camp and could not be much more modified. From a practical point of view, while acknowledging the limited magnitude of the correlation observed, present data suggest that monitoring HR during a brief submaximal constant-intensity running exercise excluding changes of direction (and to a lesser extent, postexercise HRV) could be used as an easy and noninvasive tool to approximate changes in PV when exercising in hot environments. Present findings are, however, restricted to (moderate-to-large) correlations in previously non-heat-acclimatized players; cause-to-effect relationships are therefore not straightforward.

While still debated, HR-derived indices are expected to be aversely affected by fatigue and/or any stress to the body (Borresen & Lambert, 2008; Bosquet et al., 2008). In the present study, we used plasma CK and post-5′-5′ RPE measures to estimate muscle damage and perceptual fatigue, respectively. While we acknowledge the limitation of these measures for assessing systemic stress and fatigue levels, there was no link between individual changes in these variables and changes in HR-derived indices. To our knowledge, this is the first time that the possible relationship between indices of muscle damage and HR-derived indices are examined. It is therefore possible that the sensitivity of HR measures to changes in muscle damage is not as evident as previously suggested for muscular performance (i.e. strength; Hedelin et al., 2001). It is also possible that the level of accumulated fatigue in our well-trained soccer players was not large enough to induce substantial or detectable changes in cardiac autonomic function (Bosquet et al., 2008): (1) despite significant changes in relation to training contents, mean plasma CK values remained within acceptable levels (i.e. 975 U/L; Lazarim et al., 2009) and (2) post-5′-5′ RPE was unchanged throughout the training week (Fig. 1). Taken together, present data suggest that the present in-season training/competitive week in the heat (Table 1) was likely well tolerated by the majority of the players, but that HR-derived indices might be limited to the monitoring of "central" functions (i.e. autonomic nervous system and cardiorespiratory fitness).

The beneficial effect of exercise-heat acclimation on soccer-specific physical performance in hot environment has already been demonstrated (Sunderland et al., 2008); it is, however, unknown if training in the heat can have ergogenic benefit for soccer players when playing in temperate conditions. In line with a recent study on cycling performance (Lorenzo et al., 2010), Yo-Yo IR1 running performance in temperate conditions (22°C) was improved on average by 7% after the training week. Despite the lack of control group, this improvement in Yo-Yo IR1 performance is remarkable, especially for an in-season intervention in already well-trained soccer players. First, the training contents over the 2 days preceding the Yo-Yo tests were highly similar (Table 1), and we adjusted the comparisons of Yo-Yo IR1 performance for possible individual differences in CK activity and training/playing loads before the tests so that the potential confounding effect of muscle damage and/or residual fatigue on running performance was limited (i.e. ANCOVA analysis). We acknowledge, however, that the assessment of training load via HR alone is likely limited in intermittent sports as soccer, and that additional measures during training sessions and games (e.g. time-motion analyses and session/game RPE) should be included in future studies. Second, this increase is substantially greater than the day-to-day variability in running distance for the Yo-Yo IR1 (<5%; Krustrup et al., 2003). Third, no less than 6–8 weeks of intense training are generally necessary to increase Yo-Yo IR1 performance from 15% to 35% (Bangsbo et al., 2008). Fourth, while most studies showing these large increases in Yo-Yo performance have been observed in the early preseason, the changes observed in the present study occurred after this adaptation period (i.e. in season), when physical fitness tends to plateau (Bangsbo et al., 2008; Buchheit, 2008b). While it is impossible to decipher the respective effects of heat acclimation vs training in the present study, it is therefore reasonable to suggest that (1) the observed Yo-Yo IR1 performance changes are meaningful and not just part of the normal training adaptations, and (2) heat exposure was likely to account substantially for this rapid and important change in Yo-Yo IR1 performance. It is, however, worth noting that large inter-individual responses were observed (i.e. from −5.6 to +27.2% in Yo-Yo IR1 running performance). The exact reasons for these individual responses remain to be examined with additional physiological parameters (see below), but they could be partly related to differences in training intensity distribution during the sessions/games (Castagna et al., 2011) and/or individual (intrinsic) heat acclimation responses (Ladell, 1951). Well-established adaptations to heat acclimation are reduced relative exercise intensity (Young et al., 1985), improved myocardial efficiency and, in turn, maximal cardiac output (Convertino, 1991), which are thought to be secondary to the PV expansion. In accordance with these previous observations, it may be that the changes in PV during the training camp contributed to the increase in Yo-Yo IR1 performance. However, because we did not observe any significant association between the changes in these variables, it is possible that other mechanisms (not measured here) may also explain the performance benefits from the heat acclimation. The lasting effect of such an intervention on physical performance is still unknown, and the possible detrimental impact of the reduced training intensity in hot environment on actual soccer performance has still to be evaluated.

We also observed a significant and large correlation between changes in HRex during the 5′-5′ test and changes in performance at the Yo-Yo IR1 (Fig. 2(a)). In previous studies, changes in HRR during the 5′-5′ test were largely correlated with changes in repeated-sprint ability (Buchheit et al., 2008), and changes in HRex and HRV best predicted these in maximal aerobic speed and 10-km running performance, respectively (Buchheit et al., 2010a). However, because the training intervention did not change the HRR response (see above), it was not possible to examine if this index has the potential to predict the exercise-heat acclimation-induced changes in running performance. The fact that only HRex (Fig. 2(a)) and not HRR or postexercise HRV (Fig. 2(b)(c)) measures correlated with changes in Yo-Yo IR1 performance after the training week in the heat is consistent with the underlying mechanisms of these indices. HRex is likely related to maximal cardiorespiratory function (to which Yo-Yo IR1 performance is related), while HRV measures share more determinants with endurance capacity (Buchheit & Gindre, 2006; Buchheit et al., 2010a). A closer analysis of the HR responses of the five players who did not improve their Yo-Yo IR1 performance after the competitive camp revealed, however, the limit of HRex to predict changes in running performance at the individual level (Fig. 2). For example, only one of these players showed an (expected) blunted decrease in HRex; the other four players showed a decreased HRex from 5% to 13%. These findings are nevertheless not that surprising, as (central) cardiorespiratory function is not the only determinant of high-intensity intermittent performance including changes of direction (Buchheit, 2008a). Individual differences in inter-effort recovery abilities, as well as the capacity of other neuromuscular-related factors are also likely to determine Yo-Yo IR1 performance (Bangsbo et al., 2008). Therefore, while present results show that changes in HRex during the 5′-5′ test could be used to assess globally a team's changes in soccer-specific physical fitness following an in-season competitive week in the heat, the large interindividual responses and the limited magnitude of the correlation question the use of HR measures alone to predict changes in maximal running performance at the individual level.

Perspectives

Because of the importance of technical and tactical skills in team sport such as soccer, coaches are always searching for time-efficient strategies to increase players' fitness level. Present results show that a 7-day in-season soccer training week in the heat (≈35°C) in previously non-heat-acclimatized players has the potential, at least for the majority of the players, to improve significantly PV and soccer-specific physical performance in temperate environmental conditions (22°C). Present results also encourage coaches to use submaximal running HRex as an effective noninvasive tool to examine (exercise in the heat-induced) changes in PV and physical performance. However, as outlined above, the inconsistent relationship between the changes in HR measures and either PV or Yo-Yo IR1 performance observed in some players suggests that the collection of additional data (e.g. hydration status or neuromuscular-related factors) might still be required to provide an accurate prediction of individual responses to such a training intervention. Further studies on longer periods of time and/or under other environmental conditions are still warranted to examine the lasting effect of such a training intervention on physical performance and to confirm and extend the usefulness of these HR-derived measures. The determinants of individual responses to heat acclimation in highly trained soccer players should also be examined in the future.

Key words: heart rate recovery, submaximal running test, plasma volume, creatine kinase, heat acclimation.

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