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ORIGINAL INVESTIGATION

Physiological and Performance Responses to a Training Camp in the Heat in Professional Australian Football Players

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Purpose: To examine the physiological and performance responses to a heat-acclimatization camp in highly trained professional team-sport athletes. ***Methods:*** Eighteen male Australian Rules Football players trained for 2 wk in hot ambient conditions (31–33°C, humidity 34–50%). Players performed a laboratory-based heat-response test (24-min walk + 24 min seated; 44°C), a YoYo Intermittent Recovery Level 2 Test (YoYoIR2; indoor, temperate environment, 23°C) and standardized training drills (STD; outdoor, hot environment, 32°C) at the beginning and end of the camp. ***Results:*** The heat-response test showed partial heat acclimatization (eg, a decrease in skin temperature, heart rate, and sweat sodium concentration, $P < .05$). In addition, plasma volume (PV, CO rebreathing, +2.68 [0.83; 4.53] mL/kg) and distance covered during both the YoYoIR2 (+311 [260; 361] m) and the STD (+45.6 [13.9; 77.4] m) increased postcamp ($P < .01$). None of the performance changes showed clear correlations with PV changes ($r < .24$), but the improvements in running STD distance in hot environment were correlated with changes in hematocrit during the heat-response test ($r = -.52$, 90%CI [–.77; –.12]). There was no clear correlation between the performance improvements in temperate and hot ambient conditions ($r < .26$). ***Conclusion:*** Running performance in both hot and temperate environments was improved after a football training camp in hot ambient conditions that stimulated heat acclimatization. However, physiological and performance responses were highly individual, and the absence of correlations between physical-performance improvements in hot and temperate environments suggests that their physiological basis might differ.

Keywords: acclimation, acclimatization, exercise, hot environment, temperature

Several international sporting events take place in the summer months, often in hot environmental temperatures. Most elite athletes are partly acclimatized to the heat as a result of physical training in neutral environmental conditions,[1,2] yet these adaptations are often incomplete[2] or different from those obtained with natural heat exposure[3] and do not replace acclimatization per se.[4] As a consequence, training in the heat is more efficient than either passive heat exposure or training in neutral conditions.[5] However, the optimal heat-acclimatization strategy for elite athletes is not fully understood. Indeed, the International Olympic Committee recently highlighted the importance of heat acclimatization before competition by performing training camps in hot environments but has called for further research on the specific population of elite athletes.[6]

While heat-acclimatization responses have been widely studied in work, military, and laboratory settings, there is little information from elite athletes in their natural training environment.[6] A recent study showed that a preseason altitude camp improved performance and hemoglobin mass in elite Australian Football players to a magnitude similar to that demonstrated by elite endurance athletes undertaking altitude training.[7] However, when it comes to heat acclimatization, there is high individual variability in the physiological responses of team-sport players, and athletes with the "best acclimatization responses" have been reported to gain greater performance benefit.[8] For example, it was recently shown that after a heat training camp highly trained soccer players with the greatest heat-adaptation responses were able to maintain their match physical activity profile when playing in the heat, whereas players with lower adaptation responses had a reduced activity profile compared with that in a temperate environment.[8] While that study compared a game played in the heat versus a game played in a temperate environment, the progressive effect of heat acclimatization on physical activity while playing in the heat not yet been directly measured. Consequently, the current study was conducted to determine the individual heat-acclimatization responses in professional team-sport athletes and their effects on physical activity while playing in the heat.

Moreover, heat acclimatization has also been observed to improve physical performance in temperate ambient conditions,[9–11] but the relationship between the performance changes in hot and temperate environments and the underlying mechanisms are still to be determined. It is particularly important to determine the possible ergogenic benefits of training in the heat for professional team sports (eg, soccer, Australian Football), where the time available for specific fitness sessions may be limited, as the main focus of training is often on technical and tactical aspects. Consequently, a second aim of this project was to determine whether professional athletes can gain physiological benefits from training camps in hot countries and subsequently improve their performance in both hot and temperate ambient conditions.

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Methods

Ethics Statement and Participants

Eighteen professional male Australian Rules Football (AF) players participated in this study. Their mean ± SD age, height, and body mass were 21.9 ± 2.0 years, 189 ± 8 cm, and 87.8 ± 9.1 kg, respectively. The protocol was approved by the University of Technology, Sydney, human research ethics committee and conformed to the recommendations of the Declaration of Helsinki. The players provided their written informed consent to participate in this study. During the training camp some players slept in hypoxic rooms, but there was neither clear nor substantial effect of hypoxic exposure. A 2-way ANOVA did not reveal any main effect or any interaction effect of this procedure on any of the measures reported in the current article.

Procedures

Players participated in a 14-day acclimatization camp with outdoor training in hot ambient conditions. They performed their specific AF training outdoors (29–33°C, 37–50% RH; ~1.5 h/d) and their strength and conditioning sessions indoors (~22°C; ~2 h/d). Players rested and slept in a controlled environment at 20°C to 21°C from dinner to breakfast. The camp was preceded by a day of rest (day –1) and a day of recovery training (day 0), followed by the preacclimatization tests (day 1), 10 days of training (day 2–11), and 2 days of recovery training (day 12 and 13) before the postacclimatization tests (day 14). The tests consisted of a standardized heat-response test and a physical-performance test. In addition, as part of their training, players participated in standardized training drills (STD) outside in hot ambient conditions.

Heat responses were evaluated during a 24-minute walk (5 km/h, 1% grade) followed by 24 minutes rest (seated) in a hot climatic chamber (44°C, 44% RH).[8] The same test was performed on days 1 and 14, at the same time of day (afternoon), without heat exposure in the preceding 24 hours. Average heart rate (HR; Polar Electro, Kempele, Finland), skin temperature (chest; VitalSense, Respironics, Herrsching, Germany), and thermal sensation (visual scale ranging from 0 *blue/very cold* to 20 *red/very hot*) were recorded throughout the heat-response test. Peak core temperature was recorded via an ingestible thermometer pill (VitalSense, Respironics, Herrsching, Germany). Sweat loss was calculated as the body mass before minus the body mass after the test (towel dried in underwear; Seca, Germany). Urine specific gravity was analyzed both at the beginning and at the end of the test (URC-NE, Atago, Tokyo, Japan).

Sweat samples were collected for the duration of the test from the back of each participant (Tegaderm+ Pad, 3M Health Care, Borken, Germany) and analyzed for sodium concentration ($[Na^+]_{sweat}$; Dimension Xpand Plus, Siemens, Munich, Germany).

A YoYo Intermittent Recovery test level 2 (YoYoIR2)[12] was performed indoors at the same time of day (9 AM) in temperate conditions (23°C), at the beginning (day 1, before any training in the heat) and at the end (day 14) of the acclimatization camp. All players were familiar with this test, as it was part of the regular fitness-testing battery implemented by the club. Briefly, the YoYoIR2 consists of repeated 20-m shuttle runs at increasing speeds (starting at 13 km/h), with 10 seconds of active recovery (consisting of 5 m of jogging) between runs, until exhaustion.

STDs were played outdoors (~32°C). Total distance covered, distance covered at high speed (>14.4 km/h), and HR were monitored by GPS (10-Hz, minimaxX, Catapult Innovations, Australia). Briefly, these drills consisted of 3 separate exercises of increasing complexity and intensity and were completed sequentially: (1) 4 minutes of 5-star handball drill (ie, players hand ball to every second group around a marked 5-star course; the player receiving the ball leads from the cone to receive the handball and then follows the handball to the next group; distance between cones was 8 m), (2) 5 min of 5-star "stationary" kicking drill (ie, players remained on their group's cone to receive a pass; once they marked the ball the players would kick to the next group and follow their kick; distance between cones was 15 m), and (3) 5-star kicking drill with leads (ie, same as previous drill except that players would lead from cones to receive the pass, distance 25 m). All players completed the drills under standard instructions, with a strong encouragement from the coaches, within identical playing-field dimensions and for the same duration. These drills are common training drills in AF, and the players were highly familiar with the protocols. The drills were played at the same time of day on days 2 and 5 (ie, first and fourth days of heat exposure) and on days 9 and 11 (eighth and tenth days of heat exposure). The values from the 2 sessions completed at the beginning (days 2 and 5) and at the end (days 9 and 11) of the acclimatization camp were averaged.

Plasma volume (PV) was indirectly assessed by the optimized CO-rebreathing procedure for the measurement of hemoglobin mass (Hbmass), as previously described by Schmidt and Prommer.[13] The test was conducted on rest days (day 0 and day 13). Briefly, the test comprised the inspiration of a bolus of 99.5% medical-grade CO in a dose of 1 mL/kg body mass that was rebreathed for 2 minutes. A CO sensor (Draeger PAC7000, Draeger, Luebeck, Germany) was held in close proximity to the mouth throughout the test to check for leaks. Fingertip capillary blood samples (200 μL) were analyzed in triplicate for percent carboxyhemoglobin using a spectrophotometer (ABL 80, Radiometer, Denmark) before, as well as 7 minutes after, commencing rebreathing. The resulting Hbmass was used to calculate blood volume (BV), red blood cell volume (RBCV), and PV according to the following formulas, using hemoglobin (Hb) and hematocrit (Hct) from venous blood samples: BV (mL) = [Hbmass (g)/Hb (g/dL)] × 100, RBCV (mL) = BV (mL) × (Hct/100), and PV (mL) = BV – RBCV.

Venous blood samples were also collected at the end of the 2 heat-response tests (ie, days 1 and 14). The blood was drawn in a seated position, at the 44th minute of the acclimatization test (before leaving the environmental chamber), using K2EDTA Vacutainers (Becton Dickinson, USA). Hct was analyzed within 1 hour on a Sysmex XT 2000i hematology analyzer (Sysmex, Norderstedt, Germany).

Statistical Analyses

Data were coded and analyzed in PASW software version 18.0 (SPSS, Chicago, IL, USA). The effect of the acclimatization procedure was analyzed via repeated-measure ANOVA. ANOVA assumptions were verified preceding all statistical analyses; logarithmic transformations and Greenhouse-Geisser corrections were applied where appropriate. The level of statistical significance was set at $P \leq .05$.

Effect sizes are described in terms of partial eta-squared (η^2, with $\eta^2 \geq 0.06$ representing a moderate difference and $\eta^2 \geq 0.14$ a large difference). Data are presented as mean ± SD along with the mean differences [95% confidence interval]. Given the absence of a control group, the changes in YoYoIR2 performance during the camp were also compared with historical club values obtained over the 3 preceding years (data were gathered from after off-season break, after 7 weeks of training, and after 3 months of training) using Cohen *d* (with $d \leq .2$ representing a trivial difference; .2–.5, a small difference; .5–.8, a moderate difference; and >.8, a large difference). The smallest worthwhile change was also calculated for YoYoIR2 as 0.2 × the between-players SD.[14]

Pearson product–moment correlation analysis was also used to assess the relationship between changes in performance and indices of heat acclimatization recorded during laboratory testing. The magnitude of correlation (*r* [90% confidence interval]) between test measures was assessed with the following thresholds: ≥ .3, trivial to small; >.3 to .5, moderate; >.5 to .7, large; >.7 to .9, very large; and >.9 to 1.0, almost perfect. If the 90% confidence limits overlapped positive and negative values, the magnitude was deemed unclear.[14]

Results

The $[Na^+]_{sweat}$ during the heat-response test (Table 1) decreased greatly ($\eta^2 = 0.65$, $P < .001$), resulting in a large decrease in sodium loss ($\eta^2 = 0.27$, $P = .03$) in the absence of substantial changes in sweat loss ($\eta^2 = 0.0$, $P = .98$). The heat-response test also showed large decreases ($\eta^2 \geq 0.21$, $P \leq .05$) in skin temperature, HR, and thermal sensation after the camp (Table 1). Core temperature during the test was not substantially modified ($\eta^2 = 0.02$, $P = .65$).

The heat-acclimatization camp induced a large ($\eta^2 = 0.35$) PV expansion (2.68 [0.83; 4.53] mL/kg, $P = .007$) from preacclimatization (49.8 ± 3.7 mL/kg) to postacclimatization (52.4 ± 3.8 mL/kg). However, this did not translate into substantial Hct changes at the end of the heat-response test (0.36 [–0.61; 1.33] %, $\eta^2 = 0.04$, $P = .44$). Players also displayed a large decrease in urine specific gravity after the acclimatization-camp ($\eta^2 = 0.37$, $P = .007$).

The total distance covered during the STD in a hot environment was largely increased ($P = .008$, $\eta^2 = 0.35$) during the acclimatization camp (+45.6 [13.9; 77.4] m; Figure 1), but the responses were highly individual (coefficient of variation: 140%; Figure 1). This was accompanied by a large ($P = .045$, $\eta^2 = 0.22$) increase in the amount of high-speed running (+21.6 [0.5; 42.6] m). Despite this increased activity, HR during the STD was significantly lower at the end (169 ±7 beats/min) than at the beginning (172 ±8 beats/min) of the acclimatization camp (–4 [–6; –1] beats/min, $\eta^2 = 0.41$, $P < .01$).

Table 1 Heat-Response Test

	Pre mean ± SD	Post mean ± SD	Mean difference [95% CI]
Skin temperature (°C)	39.3 ± 0.7	38.8 ± 0.3	–0.4 [–0.7; –0.1]*
Heart rate (beats/min)	109 ± 6	99 ± 7	–10 [–13; –6]*
Thermal sensation (/20)	14.5 ± 1.9	13.6 ± 1.9	–0.9 [–1.7; 0.0]*
Core temperature (°C)	37.6 ± 0.2	37.5 ± 0.1	–0.2 [–0.1; 0.1]
Urine specific gravity (g/mL)	1.018 ± 0.01	1.013 ± 0.006	–0.005 [–0.008; –0.002]*
Sweat sodium concentration (mmol/L)	80.4 ± 22.7	59 ± 20.1	–21 [–30; –13]*
Sodium loss (mmol)	55.5 ± 26.6	41.3 ± 19.8	–14 [–28; –2]*
Sweat loss (L)	0.67 ± 0.23	0.67 ± 0.17	0.0 [–0.1; 0.1]

Note: Values recorded during the heat-response test at the beginning (Pre) and end (Post) of the acclimatization camp.
*$P < .05$.

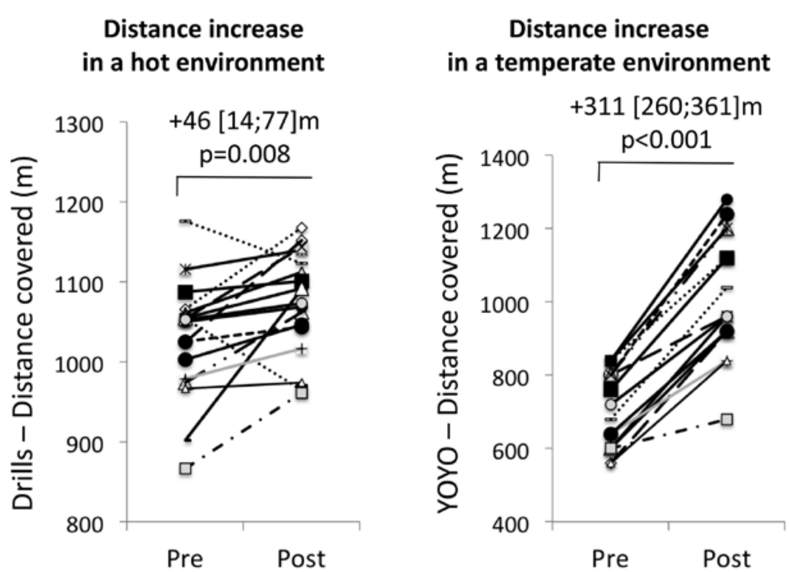

Figure 1 — Performance improvements after training in the heat. Change in running distance from the beginning (Pre) to the end (Post) of an acclimatization camp during standardized training drills in hot (left panel) and YoYo Intermittent Recovery Level 2 Test in temperate (right panel) ambient conditions. Upper values represent the mean difference [95% confidence interval]. Values increased from the beginning to the end of the acclimatization camp (both $P < .01$).

The players also exhibited a large ($P < .001$, $\eta^2 = 0.92$) increase in YoYoIR2 test performance at the end of the acclimatization camp (+311 [260; 361] m, CV: 41%; Figure 1), which was ~10 times greater than the smallest worthwhile change (~30 m). Consequently, while YoYoIR2 performance was slightly below the average preseason values from the team for the 3 previous preseasons (793 ± 177 m, Cohen *d* = .6, small difference), players achieved better performance by the end of the acclimatization than generally observed at this time of the year (Cohen *d* >.8, large difference) or even after ~7 weeks of training (982 ±164 m, Cohen *d* >.2, small difference; Figure 2).

The increases in total distance ($r = -.52$ [–.77; –.12]) and in high-speed running distance ($r = -.58$ [–.81; –.20]) during the STD were largely correlated to the changes in Hct at the end of the heat-response test from before to after acclimatization camp. However, the relationships between the changes in running performance and the changes in Hct or PV recorded at rest were unclear (ie, 90% confidence limits overlapped positive and negative values; Figure 3). The changes in high-speed running were correlated to the changes in HR ($r = .61$ [.22; .84]) and sweat loss ($r = -.58$ [–.80; –.24]), but these correlations were not observed with total distance during the STD ($-.14 \le r \le .28$). The correlations between the STD changes and the other markers of heat acclimatization, such as $[Na^+]_{sweat}$ ($r = .16$ [–.27; .54]), were also unclear.

The correlation between the performance improvements during the YoYoIR2 and STD was unclear ($r = .16$ [–.26; .53]). The changes in YoYoIR2 were moderately correlated to changes in $[Na^+]_{sweat}$ ($r = .46$ [.05; .73]) and to the age of the players ($r = .51$ [.13; .75]), but all other correlations with markers of heat acclimatization were unclear (Figure 3).

Discussion

Our data showed that 2 weeks of preseason training in hot ambient conditions elicits typical heat-acclimatization responses in professional AF players (Table 1). In addition, the distance covered during both STD in hot conditions (+5%) and YoYoIR2 in a temperate environment (+44%) were largely increased (Figure 1). The performance improvement in hot ambient condition was moderately related to the amplitude of the changes from before to after heat acclimatization during a heat-response test. In contrast, running-performance improvement in temperate conditions was not clearly correlated to the markers of heat acclimatization (Figure 3) or to the STD performance improvement in hot ambient conditions (Figure 1).

Heat-acclimatization responses have been studied in workers,[15] soldiers,[16] and athletes during controlled exercise bouts in artificial hot ambient conditions.[4,11,17] However, natural heat acclimatization is more complete than artificial acclimatization,[18] and team-sport sports performance is more complex than a controlled exercise. Therefore, the "average" heat-acclimatization pattern previously described in these studies may not account for the individual and sport-specific responses in highly trained athletes.[6] Indeed, we recently reported large interindividual variations in the ergogenic effect of an acclimatization camp in high-level soccer players.[8] The players who did not acclimatize fully had reduced running activity during a game played in a hot

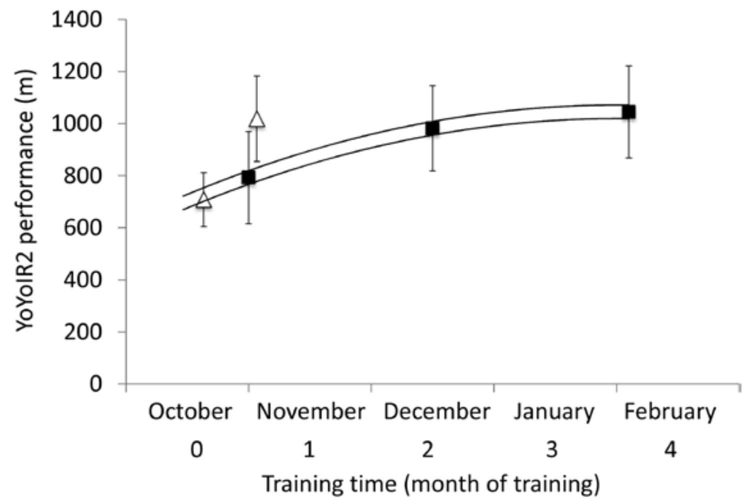

Figure 2 — Performance during a YoYo Intermittent Recovery Level 2 Test (YoYoIR2) test in temperate environment. Performance significantly increased during the heat-acclimatization camp (open triangle, +311 [260; 361] m, η^2 = 0.92, $P < .001$). Open triangles (mean ± SD) represent the preacclimatization and postacclimatization tests. Black squares (mean ± SD) and dashed lines (trivial changes) represent the historical data from the club over 3 years.

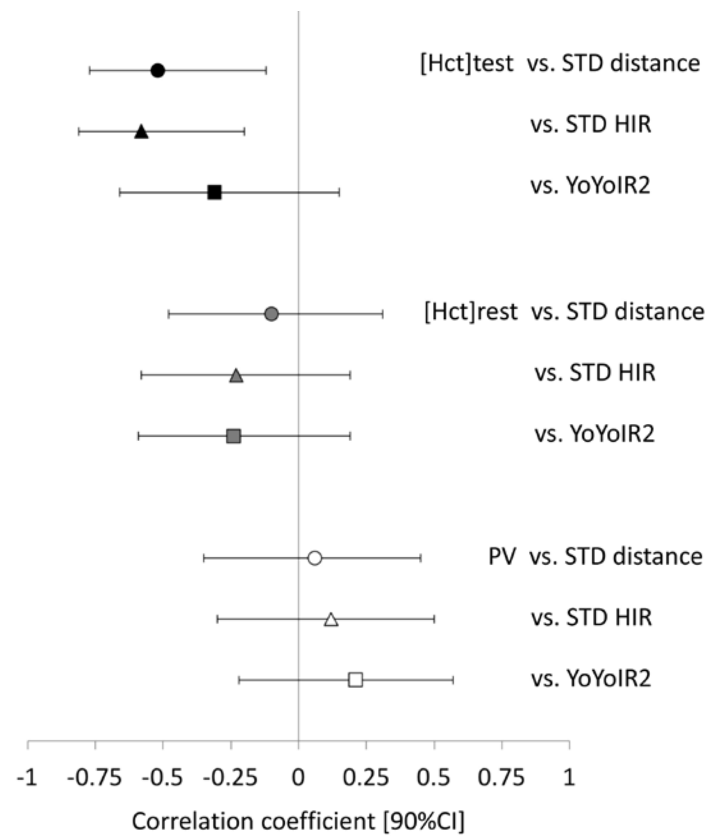

Figure 3 — Relations between running performance and acclimatization responses. Values represent the correlation coefficient (*r* [90%CI]) between the changes in running performance and the hematological response to acclimatization. Running performance was assessed in hot environment as the running distance (circles) and the high-intensity running (HIR; triangles) during standardized training drills (STD). Running performance was assessed in temperate environment as the distance during a YoYo Intermittent Recovery Level 2 (YoYoIR2) test (squares). Changes in hematocrit concentration ([Hct]) were calculated from before to after acclimatization at the end of a heat-response test (top panel) and at rest, in the morning (middle panel). Plasma volume (PV, bottom panel) was measured at rest, in the morning.

environment, and those with the best acclimatization responses were able to maintain their running activity when playing in the heat, compared with playing in a temperate environment.[8] However, in that previous study we investigated the ability to cope with soccer match play in the heat as compared with a temperate condition. In contrast, the current study examined changes in the physical activity profile of professional AF players during standardized training drills in hot conditions at the beginning and end of an acclimatization camp. In the current experiment, the technical training sessions were implemented outdoors, but the players slept and performed strength and conditioning training in temperate environments. While the ideal dose of heat exposure is still unknown, our data demonstrate that both the total distance and high-speed-running distance during STD in hot conditions improved with less than 20 hours of specific training in hot ambient conditions (Figure 1). It is, however, worth noting that it not possible to differentiate the general training effect from the specific effect of heat acclimatization in the current experiment. Nonetheless, the changes in performance were correlated to the Hct changes from preacclimatization to postacclimatization at the end of the heat-response test, confirming that this parameter may be a good indicator of the short-term heat-acclimatization response in team-sport players.[8]

There are likely many causes for the observed performance improvements after heat acclimatization in athletes. This increase cannot be simply attributed to an increased effort, as our data showed a decrease in HR despite the increase in physical activity during the STD at the end of the acclimatization camp. Moreover, the change in the amount of running in hot ambient conditions after heat acclimatization was not correlated to the increase in YoYoIR2 performance in temperate environment, the magnitude of the increase in distance covered during outdoor STD was 3 times lower than the improvement in running performance indoors, and the variability of the response was higher in hot (CV 140%) than temperate environment (CV 41%; Figure 1). These differences are likely related to the large interindividual variability in heat-acclimatization response[8] and the possibility that players might not use their full physical potential during the STD.[19]

After the camp we observed a large increase in YoYoIR2 running distance in temperate environment (Figure 1; 311 m), which was clearly greater than the smallest worthwhile change (~30 m). Note that since the current study was performed preseason without a control group, a training effect was very likely. However, this was not an issue for the current study design, since our first objective was not to assess the net effect of the intervention per se but to examine the correlations between the different individual responses to an ecologic training intervention in elite team-sport players (Figure 3). In addition, our current observations are similar to previous work performed during a midseason training camp with well-trained professional soccer players.[8,9] Anecdotally, while the players in the current study started the camp earlier in the year, together with a YoYoIR2 performance slightly below the average preseason level from the 3 previous preseasons, the YoYoIR2 performance at the end of the 2-week camp was largely greater than the historical values of the club at this time of the year or after ~7 weeks of training, and it was similar to that generally observed after 3 months of training (1045 ± 177 m, Cohen $d < .2$, trivial difference; Figure 2). These observations remain anecdotal, as some players might have changed within the squad from one year to the following one. However, while the "heat effect" cannot be separated from the "training effect" in the current experiment, our data show that preseason training camps are effective when completed in hot ambient conditions. These results agree with those of recent studies demonstrating that heat acclimatization improves physical performance in temperate ambient conditions. Hue et al[10] observed that swimmers who trained in a tropical climate had greater improvements in performance after returning to a temperate environment than swimmers who kept training in a temperate environment or at altitude. Lorenzo et al[11] demonstrated that laboratory-based acclimatization improved physical fitness and cycling performance in both hot and temperate environments. Buchheit et al[9] reported that soccer players increased their performance during a YoYoIR1 test and decreased submaximal HR response in a temperate environment after an outdoor heat-acclimatization camp. The current data showed that the magnitude of improvement during the YoYoIR2 was positively correlated to the age of the player, suggesting that training in the heat might be more beneficial for experienced players (ie, for players requiring additional stimulus or variety to optimize their training routine).

The increase in PV induced by heat acclimatization increases maximal cardiac output[20] and could account for the increase in performance during an incremental test in temperate environment.[11] However, our data failed to show any clear relationship between the performance increase during the YoYoIR2 test and PV expansion ($r = .21$ [–.21;.56]). This might be explained by previous observations that a PV expansion might increase maximal cardiac output but decrease Hb concentration by the same extent and, therefore, fail to affect maximal oxygen uptake.[21]

Conversely, the hematological adaptations observed at rest and the changes in Hct at the end of the heat-response test may reflect more complex adaptations or responses than PV increase. For instance, Hct levels at the end of the heat-response test are affected by both the hemodilution induced by acclimatization[16,22,23] and the hemoconcentration induced by exercising in hot environment.[22] Our data support previous reports suggesting that a PV increase alone is not sufficient to improve thermoregulatory function[24,25] but confirm that the Hct changes at the end of a heat-response test represent a valuable multifactorial marker of heat acclimatization.[8]

Heat acclimatization leads to various other physiological adaptations that could explain the physical-performance improvements. For example, heat acclimatization lowers HR and respiratory exchange ratio during exercise in the heat,[26] as well as reducing metabolic rate along with muscle and blood lactate accumulation during exercise in both temperate and hot ambient conditions.[27] There is, however, no direct evidence that these observations during submaximal exercise would translate into a physical-performance improvement while playing football. Finally, our data also showed a moderate correlation between the magnitude of heat acclimatization estimated by the changes in $[Na^+]_{sweat}$ and the improvement in YoYoIR2 performance, but physiological mechanisms behind such a relationship remain to be determined.

Conclusion

The current data showed that AF training in hot ambient conditions induces several adaptations consistent with heat acclimatization. Running performance in both hot and temperate environments was also substantially improved after the camp. However, while individual performance changes in the heat correlated with some marker of heat acclimatization, the changes in running performance in hot and temperate conditions did not correlate. Collectively, these findings show that professional team-sport athletes can gain ergogenic benefits from training camps in hot environments, irrespective of whether they compete in hot or temperate climates. Note, however, that the magnitude of the benefit might depend on different mechanisms.

Practical Implications

- A training camp in hot ambient conditions induces heat acclimatization and largely improves physical performance in professional AF players.
- Players can gain ergogenic benefits from organized training camps in hot environments, irrespective of whether they compete in hot or temperate climates.

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References

1. Piwonka RW, Robinson S, Gay VL, Manalis RS. Preacclimatization of men to heat by training. *J Appl Physiol*. 1965;20:379–383. PubMed
2. Gisolfi C, Robinson S. Relations between physical training, acclimatization, and heat tolerance. *J Appl Physiol*. 1969;26:530–534. PubMed
3. Nadel ER, Pandolf KB, Roberts MF, Stolwijk AJ. Mechanisms of thermal acclimation to exercise and heat. *J Appl Physiol*. 1974;37:515–520. PubMed
4. Strydom NB, Wyndham CH, Williams CG, et al. Acclimatization to humid heat and the role of physical conditioning. *J Appl Physiol*. 1966;21:636–642. PubMed
5. Armstrong LE, Maresh CM. The induction and decay of heat acclimatisation in trained athletes. *Sports Med*. 1991;12:302–312. PubMed doi:10.2165/00007256-199112050-00003
6. Bergeron MF, Bahr R, Bärtsch P, et al. International Olympic Committee consensus statement on thermoregulatory and altitude challenges for the high-level athlete. *Br J Sports Med*. 2012;46:770–779. PubMed doi:10.1136/bjsports-2012-091296
7. McLean BD, Buttifant D, Gore CJ, White K, Liess C, Kemp J. Physiological and performance responses to a preseason altitude-training camp in elite team-sport athletes. *Int J Sports Physiol Perform*. 2013;8(4):391–399. PubMed
8. Racinais S, Mohr M, Buchheit M, et al. Individual responses to short-term heat acclimatization as predictors of football performance in hot dry environment. *Br J Sports Med*. 2012;46:810–815. PubMed doi:10.1136/bjsports-2012-091227
9. Buchheit M, Voss SC, Nybo L, Mohr M, Racinais S. Physiological and performance adaptations to an in-season soccer camp in the heat: associations with heart rate and heart rate variability. *Scand J Med Sci Sports*. 2011;21(6):e477–e485. PubMed doi:10.1111/j.1600-0838.2011.01378.x
10. Hue O, Antoine-Jonville S, Sara F. The effect of 8 days of training in tropical environment on performance in neutral climate in swimmers. *Int J Sports Med*. 2007;28:48–52. PubMed doi:10.1055/s-2006-923958
11. Lorenzo S, Halliwill JR, Sawka MN, Minson CT. Heat acclimation improves exercise performance. *J Appl Physiol*. 2010;109:1140–1147. PubMed doi:10.1152/japplphysiol.00495.2010
12. Bangsbo J, Iaia FM, Krustrup P. The Yo-Yo Intermittent Recovery Test: a useful tool for evaluation of physical performance in intermittent sports. *Sports Med*. 2008;38:37–51. PubMed doi:10.2165/00007256-200838010-00004
13. Schmidt W, Prommer N. The optimised CO-rebreathing method: a new tool to determine total haemoglobin mass routinely. *Eur J Appl Physiol*. 2005;95:486–495. PubMed doi:10.1007/s00421-005-0050-3
14. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41:3–13. PubMed doi:10.1249/MSS.0b013e31818cb278
15. Fox RH, Goldsmith R, Kidd DJ, Lewis HE. Acclimatization to heat in man by controlled elevation of body temperature. *J Physiol*. 1963;166:530–547. PubMed
16. Ladell WSS. Assessment of group acclimatization to heat and humidity. *J Physiol*. 1951;115:296–312. PubMed
17. Nielsen B, Hales JRS, Strange S, Christensen NJ, Warberg J, Saltin B. Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. *J Physiol*. 1993;460:467–485. PubMed
18. Edholm OG. The physiology of adaptation. *Eugen Rev*. 1966;58:136–142. PubMed
19. Buchheit M, Mendez-Villanueva A, Simpson BM, Bourdon PC. Match running performance and fitness in youth soccer. *Int J Sports Med*. 2010;31:818–825. PubMed doi:10.1055/s-0030-1262838
20. Gledhill N, Warburton D, Jamnik V. Haemoglobin, blood volume, cardiac function, and aerobic power. *Can J Appl Physiol*. 1999;24:54–65. PubMed doi:10.1139/h99-006
21. Kanstrup IL, Ekblom B. Blood volume and hemoglobin concentration as determinants of maximal aerobic power. *Med Sci Sports Exerc*. 1984;16:256–262. PubMed doi:10.1249/00005768-198406000-00010
22. Harrison MH, Edwards RJ, Graveney MJ, Cochrane LA, Davies JA. Blood volume and plasma protein responses to heat acclimatization in humans. *J Appl Physiol*. 1981;50:597–604. PubMed
23. Senay LC. Plasma volumes and constituents of heat-exposed men before and after acclimatization. *J Appl Physiol*. 1975;38:570–575. PubMed
24. Sawka MN, Coyle EF. Influence of body water and blood volume on thermoregulation and exercise performance in the heat. *Exerc Sport Sci Rev*. 1999;27:167–218. PubMed
25. Watt MJ, Garnham AP, Febbraio MA, Hargreaves M. Effect of acute plasma volume expansion on thermoregulation and exercise performance in the heat. *Med Sci Sports Exerc*. 2000;32:958–962. PubMed doi:10.1097/00005768-200005000-00013
26. Febbraio MA, Snow RJ, Hargreaves M, Stathis CG, Martin IK, Carey MF. Muscle metabolism during exercise and heat stress in trained men: effect of acclimation. *J Appl Physiol*. 1994;76:589–597. PubMed
27. Young AJ, Sawka MN, Levine L, Cadarette BS, Pandolf KB. Skeletal muscle metabolism during exercise is influenced by heat acclimation. *J Appl Physiol*. 1985;59:1929–1935. PubMed