

**Effects of Heat Acclimatization Training on Football Performance:
Evaluating Endurance, Speed, and Recovery in University Players from Hot Climates**

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ABSTRACT

The present study investigated the effects of 8-week heat acclimatization training (HAT) program on the main performance metrics of the university Football players from the hot area. Population of the study comprised of 46 male players, age 18-25 years, from two different academies of Lahore. Using randomized controlled design, participants were assigned to either experimental (HAT) group (n = 23) or the control group (n = 23). Experimental group completed the five weekly 90-minute sessions of HAT in the controlled environmental conditions (30-35°C, 50-60% relative humidity), incorporating Football-specific drills at progressively increasing intensities (60-85% HRmax). The control group followed their previous standard training schedule. Normality of data was confirmed using Shapiro-Wilk tests (all $p > 0.05$). Pre- and post-intervention assessment was conducted for muscular endurance by Yo-Yo intermittent recovery test level 1, sprint performance by 30m sprint test, cardiovascular recovery by heart rate recovery test at 1-minute post-exercise, and perceived fatigue by the Borg CR-10 scale. Cross examination of pre- and post-test date revealed that experimental group demonstrated significant improvements in all measured variables including muscular endurance increased by 21.9% ($p < 0.001$, $d = 1.42$), sprint time decreased by 5.4% ($p = 0.003$, $d = 0.85$), heart rate recovery improved by 27.3% ($p < 0.001$, $d = 1.30$), and perceived fatigue decreased by 22.7% ($p < 0.001$, $d = 1.55$). Whereas participants of the control group showed no significant changes in any performance metric (all $p > 0.05$). Between-group comparisons demonstrated significantly greater improvements in the HAT group for all outcomes ($p < 0.01$). These findings confirm that structured HAT induces substantial physiological adaptations which enhance Football-specific performance in hot environments particularly during preseason preparation. The large effect sizes across all variables suggest that these improvements are practically meaningful for Football players. Future research should investigate the perseverance of these adaptations across competitive seasons and examine possible gender differences in heat acclimatization responses.

Keywords: Temperature, Adaptation, Physiological, Modalities, Performance, Metrics

INTRODUCTION

During hot and humid environment, decline is likely to occur in sports performance (Guy et al., 2015). Football is the game of strenuous physical exertion and during hot and humid season, players face physiological strain and hardships which alternately impair their overall performance and decision-making ability (Kang et al., 2024). Maintaining performance up to the mark in Football requires well-tailored conditioning modalities to better cope with the physical needs of the environment. Physical exertion of the Football players during high ambient temperatures ($>30^{\circ}\text{C}$) poses challenging demand simultaneously on the thermoregulatory as well as cardiovascular functioning that often leads to premature fatigue, rise in body temperature and dehydration (Martschinske, 2011). Resultantly these factors not only affect the working capacity negatively but they also enhance the risk of injuries in the regions like South Asia particularly Pakistan, where training and competitions are conducted in thermally stressful conditions (Maughan et al., 2010). In global scenario, where growing emphases are placed on optimizing the overall sports performance, heat acclimatization training (HAT) has attained wide recognition as an effective remedy to mitigate the heat-related performance decrements and to improve the physiological resilience (Di Domenico, 2023). HAT plays significant role in sports resulting in enhanced thermoregulation in terms of improved sweating and lower core temperature Kim and Park, (2004), better cardiovascular efficiency in shape of increased plasma volume and reduced heart rate Dong (2016); and improved sports performance in the form of greater endurance, faster recovery and reduced fatigue (Wiewelhove et al., 2015).

A number of adaptation related advantages are directly associated with heat acclimatization including earlier onset of sweating, enhanced sweat rate and expansion of improved plasma volume and they all play significant role in better thermoregulation (Lim, 2020). In addition to that, Aylwin (2022) has concluded that HAT reduces cardiovascular strain through decreasing heart rate during submaximal exercise and subsequently improving the stroke volume. Most of the existing literature highlights the implication of HAT to endurance athletes whereas applicability of HAT to the Football players remains less explored (Ortiz et al., 2024). In technical perspectives, performance in Football depends mainly on recurrent high-intensity exertion like sprinting, jumping and high level of agility for rapid directional changes. The potential advantages of HAT in improving the key performance indicators like endurance, recovery kinetics and sprint speed warrant further investigations (Hall et al., 2024).

In spite of the established advantages of HAT, dis-opinion still exists regarding the frequency, intensity and duration to heat exposure for the adaptation of Football players (Debney, 2021; Gale, 2020; Judge et al., 2025). Additionally, majority of the HAT related protocols have been derived from the marathon runners and military people who differ from the key dynamics of Football (Bullock et al., 2010). Employing HAT, past studies conducted about sports performance, temperature and climatic effects have demonstrated improvement in performance, limited evidence exists from the tropical and subtropical regions, where players may already have limited heat adaptation on account of routine environmental exposure (Hue, 2011). This type of research gap in the existing literature warrants the basic question whether employment of structured HAT can further enhance performance of those players who are already and partially heat-experienced.

Main objective of the present study was to address the existing gap by investigating the effects of 8-week HAT program on the sprint performance, muscular endurance, fatigue resistance and post exercise recovery among the university Football players from Lahore, Pakistan; the city characterized by lengthy spells of heat accompanied by humidity. According to Weather Spark the average normal temperature in Lahore during the summer remains around 38°C (100°F). It was hypothesized that systematic HAT program would lead to significant improvements in these performance metrics in comparison to the traditional training approaches. Findings of the present study could provide research-based insights to the coaches and sports practitioners looking for optimizing training modalities for the Football players particularly in the hot and humid areas, ultimately improving sports performance and minimizing heat-related health risks.

MATERIALS AND METHODS

Participants

For the present randomized control trial, 46 male university Football players having age between 18-25 years were recruited from two different professional training academies in Lahore. Inclusion criteria for the participants included three consecutive years of playing competitive Football experience and with no medical history particularly about cardiovascular or heat-related illness. After the baseline assessments, participants were randomly assigned to either experimental (HAT) group (n=23) which underwent through the HAT, or the control group (n=23) which was not given any specialized training rather they continued their routine Football training without extra heat exposure. Computer-generated block randomization was used for randomization of the participants to ensure balanced group allocation. Participants were informed about the purpose and process of the study and prior to the start of the study, written informed consent was obtained from all the respondents.

Intervention Protocol

Participants of the experimental group underwent 8-week heat acclimatization training program which consisted of five sessions per week, each session of 90-minutes. The training was conducted under an environmentally controlled training environment maintained between 30-35°C and the humidity allowance was maintained between 50–60%. Each training session was carefully planned to gradually increase cardiovascular and thermal stress while closely observing the participants for any sign of heat intolerance during the activity. Drills of the training were designed in a way to practice and repeat the real Football actions like intermittent speed running, agility activities like sudden directional changes and jumping actions. To monitor the exercise intensity, Polar H10 was used to confirm that participants performed within 60-85% of the maximum heart rate (MHR) which was determined during the preliminary graded exercise testing. Hydration of the participants was maintained standardized with players consuming 5-7 ml/kg of water before entering the training session and during training, they were allowed to drink as much electrolyte drink as they wanted to drink. To ensure safety of the participants during the entire course of training, core body temperature of the participants was measured using ingestible telemetric pills that transmits temperature data, and participants also rated how hard they felt they were working, using a standard scale for measuring perceived exertion (Borg RPE scale). The control group continued to follow their regular routine of training practice which also consisted of five weekly sessions, each lasting 90 minutes at normal room temperature (25-28°C) following the same Football-specific drills. Both groups of the study underwent through the similar strength and conditioning training regimen (two resistance sessions per week) to highlight the effects of heat acclimatization on the participants.

Outcome Measures

The following three main outcome variables were investigated during the study.

1. **Muscular Endurance** To assess the high-intensity intermittent running capacity of the participants, Yo-Yo Intermittent Recovery Test Level 1 (YYIRT1) was employed. Participants ran the recurrent 20-meter shuttle run at gradually increasing the speeds with a rest period of 10-seconds between each two 20-meter runs. The moment the test concluded when the participants failed twice to timely reach the finishing line. As a result of this activity, total distance covered by each respondent was noted as the primary outcome.
2. **Sprint Performance** Electronic timing gates (Brower Timing Systems) was used to assess the performance of each participant in 30-meter sprint test which was conducted on a grassy field. Each participant performed three sprint trials availing 3-minutes recovery interval between the trials. Out of the three trials, the fastest time of each participant was recorded. Objective of this test was to assess the anaerobic speed capacity of the respondents which is one of the basic determinants of performance in Football.

3. Post-Exercise Recovery Heart rate recovery (HRR) or Post-exercise recovery determines efficacy of the cardiovascular and cardio-respiratory systems which is vital in sports performance. HRR is associated with the ability of heart to get back sooner to its normal state of functioning. Following the established way of its measurement, HRR of the participants was measured immediately after a standardized 5-minute submaximal run at 70% HRmax. Heart rate was recorded once again after one minute of the activity. And the difference between the first and second recorded figure was taken as the HRR of the participants.

RESULTS

Data Normality Test

Prior to the statistical analysis of data, Shapiro-Wilk test was conducted to test all the dependent variables for the normal distribution. All variables included in the study met the assumption of normality ($p > 0.05$), which allows the use of parametric test for the subsequent analysis of data.

Table 1: Shapiro-Wilk Test for Normality

Variable	Group	W-statistic	p-value
Muscular Endurance (m)	HAT	0.972	0.678
	Control	0.965	0.543
Sprint Time (s)	HAT	0.984	0.892
	Control	0.978	0.781
HRR (bpm)	HAT	0.961	0.462
	Control	0.969	0.612
Fatigue (Borg CR-10)	HAT	0.955	0.385
	Control	0.963	0.497

Since all p-values were > 0.05 , the data were normally distributed, satisfying the assumption for parametric tests (paired and independent t-tests).

PERFORMANCE OUTCOMES

Muscular Endurance (Yo-Yo IR1 Test)* (Bangsbo et al., 2008)

Table 2: Muscular Endurance Changes (in meters)

Group	Pre-test (Mean \pm SD)	Post-test (Mean \pm SD)	Mean Difference	p-value	Effect Size (d)
HAT	1280 \pm 210	1560 \pm 190	+280	<0.001	1.42 (Large)
Control	1260 \pm 200	1300 \pm 180	+40	0.210	0.20 Small)

*Yo-Yo IR1 Test: It is the Intermittent Recovery Level 1 test that assesses ability of the athlete to repeatedly perform high-intensity runs followed by short recovery periods.

Participants of the HAT group have shown significant improvement in the muscular endurance ($p < 0.001$) with a large effect size ($d = 1.42$), reflecting a substantial positive effect of training intervention. The control group has shown a minimal change ($p = 0.210$), confirming that standard training alone does not enhance endurance.

Sprint Performance (30m Sprint Test)

Table 3: Sprint Time Changes (in seconds)

Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Mean Difference	p-value	Effect Size (d)
HAT	4.25 ± 0.30	4.02 ± 0.25	-0.23	0.003	0.85 (Large)
Control	4.28 ± 0.32	4.26 ± 0.30	-0.02	0.720	0.06 (Trivial)

Table 3 depicts that participants of the HAT group significantly reduced sprint time ($p = 0.003$) with a large effect size ($d = 0.85$), suggesting improved anaerobic speed. On the other hand, control group had no significant improvement ($p = 0.720$), reaffirming that heat acclimatization contributed to improvement in speed.

Heart Rate Recovery (HRR)

Table 4: HRR Changes in beat per minute

Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Mean Difference	p-value	Effect Size (d)
HAT	22 ± 5	28 ± 4	+6	<0.001	1.30 (Large)
Control	21 ± 6	22 ± 5	+1	0.450	0.18 (Small)

Table 4 shows that HAT group demonstrated significantly faster HRR ($p < 0.001$) with a very large effect size ($d = 1.30$), indicating enhanced cardiovascular recovery. However, on the contrary, control group showed no significant change ($p = 0.450$), confirming that heat exposure was necessary for improved recovery.

Perceived Fatigue (Borg CR-10 Scale)

Table 5: Perceived Fatigue Changes

Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Mean Difference	p-value	Effect Size (d)
HAT	7.5 ± 1.2	5.8 ± 1.0	-1.7	<0.001	1.55 (Large)
Control	7.6 ± 1.1	7.4 ± 1.0	-0.2	0.380	0.19 (Small)

Table 5 reveals that HAT group reported significantly lower fatigue ($p < 0.001$) with a very large effect size ($d = 1.55$), suggesting better heat tolerance in the participants. The control group had no significant change ($p = 0.380$), indicating that standard training did not reduce perceived exertion.

Between-Group Comparisons (Independent t-tests)

Table 6: Post-Test Differences Between HAT vs. Control

Variable	HAT (Mean ± SD)	Control (Mean ± SD)	Mean Difference	p-value	Effect Size (d)
Muscular Endurance (m)	1560 ± 190	1300 ± 180	+260	<0.001	1.40 (Large)
Sprint Time (s)	4.02 ± 0.25	4.26 ± 0.30	-0.24	0.005	0.88 (Large)
HRR (bpm)	28 ± 4	22 ± 5	+6	<0.001	1.35 (Large)
Fatigue (Borg CR-10)	5.8 ± 1.0	7.4 ± 1.0	-1.6	<0.001	1.60 (Large)

Table 6 presents a summary picture of all variables. All post-test comparisons were statistically significant ($p < 0.01$) with large effect sizes ($d > 0.8$). This confirms that HAT was superior to standard training in improving endurance, speed, recovery, and fatigue resistance.

Summary of the Findings

- a. Heat acclimatization training (HAT), followed by the participants of the experimental group, significantly improved all the performance metrics compared to the standard training followed by the participants of the control group.
- b. Effect sizes were large ($d > 0.8$), indicating practical significance for Football training in hot climates.
- c. No significant improvements were observed in the participants of the control group, confirming that heat exposure was the key factor driving adaptations.

These results strongly support the integration of structured HAT into Football training programs for players in the hot environments.

DISCUSSION

The present 8-week long experimental study has confirmed that HAT program has significantly improved all the dependent variables including cardiovascular recovery, sprint performance, muscular endurance and fatigue resistance in the Football players from hot climate. Findings of the study corroborate the findings of the previous studies confirming that repetitive exposure to heat improves the thermoregulatory efficacy and sports performance in the players (Chalmers et al., 2014; Périard et al., 2024). Additionally, the large effect sizes shown across all the variables measured in the study suggest that employment of HAT resulted in significant physiological adaptation which are literally very useful and productive for the overall performance in Football particularly in the hot and thermally humid environment.

Additionally, table 2 depicts an improvement of 21.9% in the Yo-Yo IR1 performance among the respondents included in the HAT group ($p < 0.001$) which supports findings of the study of Delahunt et al. (2013) who have confirmed an increase of 15-25% in the capacity of the respondents for the intermittent running in a 4-6 weeks HAT program given to the soccer player. Improved cardiovascular efficiency and plasma volume expansion seem to be the main factors for this type of adaptation which ensure prompt delivery of oxygen during intense physical exertion (Garrett, 2023). Further that, as supported by Lynch (2023), the decline in the core body temperature during exertion of high-intensity is associated with the well-established output of heat acclimatization and that may have resisted the onset of fatigue during the intermittent sprints. Intermittent sprint is considered to be the part and parcel of Football players. HAT also has significant role in improving the sprint performance through improving muscular efficiency and lowering cardiovascular strain particularly during the hot conditions

Findings of the study have confirmed a significant reduction (-5.4%, ($p = 0.003$) in the 30-meter sprint time (Table 3) which are aligned with the findings of de Sousa et al. (2022), who have documented that incorporating agility drills in HAT program designed for the Football players during hot conditions enhanced the sprint performance by 4-6% However, findings of the study by Sekiguchi et al. (2022) contradict with the findings of the present study who claim no change in the post-HAT in the anaerobic performance. This inconsistency in the findings is likely to be linked with the nature and differences in the specificity of trainings. The training offered in the present study employed real Football oriented exercises in the hot conditions not just passing time in the hot environment. Resultantly, players adapted to the heat while practicing Football-specific activities.

Cardiovascular recovery and sports performance are co-related; the faster is the Cardiovascular recovery the better is the sports performance. Heat acclimatization trains heart and improves its ability to return faster to normal functioning state enabling the player to consistently perform repeated explosive movements efficiently with shorter rest periods. Findings of the study have shown 27.3% improvement in the heart rate recovery (HRR) of the participants of the experimental group which corroborate the findings of Slattery

and Coutts (2019), who confirmed improvement in the parasympathetic reactivation after employing the HAT program. Better HRR is vital for the Football players as it allows the player for sustained performance during competition (Dai & Xie, 2023).

Action, exertion and fatigue are the main features of play life. Heat acclimatization delays fatigue, allowing the player to perform at the best of their ability which is key to quality performance in Football. Findings of the study (Table 5) confirm visible decrease in the Borg CR-10 ratings (-22.7%, $p < 0.001$) supporting findings of the study of Coyne et al. (2021), who have documented that acclimatized athletes reported lower reduced perceived fatigue (RPF) as compared to non-acclimatized athletes following workload of the same nature. On account of the state of adaptation of the players, they felt less exhaustion as their bodies better resisted heat. This main factor behind all this situation was the role of HAT which made hot conditions feel easier and allowing the players to concentrate on the game rather than combating the discomfort of heat.

The present study endorses the positive role of HAT, a few studies oppose its efficacy claiming that the athletes, particularly from the tropical regions, who are often naturally heat-adapted may not have any notable benefit from using the HAT (Daanen et al., 2018). Nevertheless, participants of the present study were from the hot climate, even then they exhibited substantial enhancement in different metrics of performance in Football which suggests that HAT has the capacity to optimize sports performance of the heat-adapted players. Contrasting findings of the present study that HAT enhance both aerobic and anaerobic attributes crucial for Football, Pryor et al. (2023) have concluded that HAT benefits are mostly associated with the endurance performance rather than team-sports. Findings of the present study support integration of the HAT into the training regimes of Football particularly in the hot regions. Coaches and sports practitioners should progressively introduce exposure of the players to heat (30-35°C) for a period of 4-8 weeks. Additionally, they should prioritize HAT with the Football-specific drills to get more benefits in the future.

LIMITATIONS

Population of the study comprised of the male participants, prospects of its generalizability of its findings are confined only to male players. Adaptation characteristics of male differ from female on account of hormonal effects on thermoregulation (Charkoudian & Stachenfeld, 2014). Participants of the present study were from Lahore which don't represent different hot climates of the country. Périard et al. (2015) have concluded that cope the region representation issue, comparative studies need to be conducted across different tropical regions. Since intervention of 8-week was employed in the present study and it showed significant improvement in terms of adaptation to the heat, however, durability of the present adaptability is a matter which is unknown. To overcome this flaw, longitudinal studies assessing adaptation to heat across different seasons need to be conducted to further strengthen the findings (Brown et al., 2022).

CONCLUSION

In view of the evidence-based findings of the study it is concluded that HAT plays significant role in the improvement of key performance-metrics in the university Football players. These performance components include sprint performance, cardiovascular recovery, muscular endurance, and fatigue resistance in the participants of the study training in hot climates. Additionally, the large effect sizes noted for the different variables measured in the study (Cohen's $d > 0.8$) (Cohen, 2013) highlight HAT's practical relevance for the players who usually take part in sports competitions hot and humid environment. The aforementioned improvement in various bodily attributes is the output of the post-HAT participation which can be attributed to the internal biological adaptation of different functional systems of the body. These physiological adaptations include improved cardiovascular stability, enhanced volume of plasma and improved thermoregulatory efficacy, which play vital role in yielding better performance in hot and humid environment (Périard et al., 2021). Heat acclimatization training enables the body to better cope the stresses caused by the hot conditions through the enhanced performance of the built-in cooling system of the body.

Conversely, the control group did not show any significant improvement in terms of adaptation to heat, which confirms that integration of the structured HAT into pre-season and in-season training protocols without heat exposure is crucial for gaining maximum performance benefits. It will enable the players to work efficiently for a longer period of time, ensure rapid recovery and reduce the early onset of fatigue. However, coaches and sports practitioners should remain careful while implementing Heat Acclimatization Training program about the state of proper hydration and best output of the players (Judge et al., 2025). Future research should focus on role of HAT in gender-based differences and exploring the kinetics of long-term adaptation in different games as literature confirms that female demonstrate different types of responses to thermoregulatory adaptations (Doohan et al., 2025).

Ethical Approval

The study was approved by the Ethics Committee of the Department of Sports Sciences and Physical Education, Faculty of Allied Health Sciences, The University of Lahore, with approval code *DSSPE/ECA/2025-70*.

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Conflicts of Interest

The authors declare no conflicts of interest.

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