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Beyond the forecast
Climate-smart strategies for football performance

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Στην εποχή της κλιματικής αλλαγής: Έξυπνες στρατηγικές για υψηλή ποδοσφαιρική απόδοση

Περίληψη στο τέλος του άρθρου

Key words: Athletic performance, Climate change, Cold exposure, Football, Heat stress

Scientific evidence confirms that extreme weather events, such as heatwaves and cold spells, are becoming more frequent due to climate change.[1] Football, as a year-round outdoor sport with extended match durations, is particularly vulnerable to these conditions. A notable example is the United Kingdom's (UK) spring of 2018, which saw extreme cold followed by sudden high temperatures,[2] highlighting the unpredictable nature of modern weather patterns. Such rapid climatic shifts can impair athletes' physiological adaptation, affecting performance, recovery, and safety.[3] The need for flexible, evidence-based adaptation strategies is critical, especially in football, where players are exposed to varying environmental conditions throughout the season. Beyond performance, climate variability influences injury risk, recovery protocols, and tactical planning. This necessitates a scientific, proactive approach to training and competition design, integrating physiological insights and environmental monitoring. This article outlines evidence-based strategies to manage heat and cold stress, ensuring safety and performance in football under extreme weather conditions.

Football players' exposure to high temperatures and humidity presents serious challenges to both health and performance. Prolonged exertion in such environments can lead to dehydration, heat exhaustion, and even heat stroke, conditions associated with increased cardiovascular strain and diminished competitive capacity.[4] To assess and mitigate risk, the wet-bulb globe temperature (WBGT) index –factoring humidity, radiant heat, and air temperature– is widely used.[5] To address heat stress effectively, scientifically validated strategies are recommended. These include pre-hydration 2–3 hours before competition and consistent intake of fluids containing electrolytes during activity.[6] Equally important is the use of lightweight, breathable clothing and sun protection, along with the implementation of cooling breaks, especially when ambient temperatures exceed 30 °C, in accordance with FIFA guidelines.

Heat cramps, a frequent issue during intense effort in hot conditions, result from fluid and electrolyte loss –particularly sodium– through excessive sweating.[3] They typically affect overworked muscles such as the calves, hamstrings, and abdominals, often occurring during or shortly after prolonged physical activity. Prevention and management involve regular electrolyte intake, gentle stretching of affected muscles, and temporary cessation of activity to allow for rehydration and recovery.

A key long-term intervention is heat acclimatization, a process of gradually increasing exposure to elevated temperatures over a 7 to 14-day period.[7] This adaptation improves the body's thermoregulatory efficiency, lowers physiological strain, and enhances tolerance to heat, ultimately supporting sustained athletic performance in hot environments.

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Human physiology is not inherently adapted to cold environments, making exposure to low temperatures particularly demanding for both biological functions and athletic performance. The body's immediate response to such conditions includes peripheral vasoconstriction, aimed at reducing heat loss through the skin. As a result, the temperature of the extremities decreases, rendering them especially vulnerable to cold-induced strain.[8] During prolonged exposure to cold, thermoregulatory mechanisms are activated, such as shivering thermogenesis and non-shivering thermogenesis, in order to maintain core temperature (Tc) at normal levels (approximately 37 °C). However, in extremely cold environments where heat loss exceeds the body's ability to compensate, there is a gradual decline in Tc, which may lead to cognitive impairment, metabolic dysregulation, and, in extreme cases, multisystem failure.[8] Managing the effects of cold on football players requires the implementation of combined strategies. These include the use of appropriate clothing (thermal underwear, insulated socks, gloves), maintaining mobility during the match to ensure circulation and thermal balance, providing heated rest areas and warm beverages at halftime, as well as the continuous monitoring of thermal indicators such as skin and core temperature using specialized sensors.

Particularly important is the process of cold acclimation through gradual exposure to cold environments. It has been documented that such acclimatization reduces the intensity of shivering and enhances the body's ability to generate heat without activating shivering mechanisms,[9] providing direct benefits in terms of energy conservation and maintenance of athletic performance. Cold acclimation, achieved through gradual exposure over several weeks (unlike heat acclimatization, which typically requires 7–14 days), reduces shivering intensity and enhances non-shivering thermogenesis.[9] This adaptation conserves energy and helps maintain athletic performance in cold environments. For athletes, this implies preseason cold exposure protocols should begin weeks before competition in cold climates.

Adapting athletic activity to increasing climate variability has become a critical factor in maintaining athletes' health and performance. Scientific evidence clearly indicates that extreme weather events –whether heatwaves or cold spells– are occurring with increasing frequency and intensity in recent decades, significantly affecting the athletic calendar, competition conditions, and the biological demands on participants.[1] In this context, the need for a strategic adaptation of the training process is more relevant than ever, as it can substantially contribute to enhancing athletes' resilience and reducing the risk of heat- or cold-related strain.[7] A holistic approach includes educating coaches and players on early signs of heat exhaustion, hypothermia, and related disorders, thereby strengthening preventive measures. Simultaneously, adjusting training duration and intensity to the climatic conditions of each region can enhance physiological tolerance and performance. Emphasis is placed on technological tools –GPS systems, thermal sensors, and microclimate logging– that enable real-time assessment of environmental load and informed decisions. Implementing individualized adaptation protocols (e.g., heat or cold acclimation) based on scientific standards may provide a significant advantage in high-stress environments. Adaptation to climate variability is not a one-off solution but a continuous, dynamic process of prevention and management requiring collaboration among sports scientists, coaching staff, and administrators. In modern football, where competitions occur year-round across varying climates, integrating these practices is essential to protect athletes and ensure competition continuity under safe and effective conditions. Refer to table 1 for a comparative overview of environmental strategies.

In conclusion, extreme temperatures pose significant risks to football players' performance and safety. Practical

Table 1. Comparative table of measures for football in extreme temperatures.

Category	Cold environment strategies	Heat and humidity strategies
Warm-up and preparation	Extended and intense warm-up to raise core temperature[7]	Short-duration warm-up to avoid early overheating[9]
Clothing	Thermal underwear, gloves, insulated socks[7]	Lightweight, breathable clothing; hats and sunscreen during warm-up[4]
Hydration	Warm fluid before and after the match[7]	Electrolyte-rich fluids before and during play[5]
Breaks and match management	Maintain activity to prevent hypothermia[7]	Cooling breaks; reduce exertion during peak heat[4]
Rest and recovery	Heated rest areas; warm drinks at halftime[7]	Shade, fans, or cooled environments at halftime[7]
Physiological adaptation	Cold acclimation through progressive exposure[8]	Heat acclimatization over 7–14 days[3]
Technological support	Temperature and shivering monitoring via sensors[7]	Core temp and sweat monitoring with wearable tech[7]

measures, such as hydration strategies, acclimatization protocols, appropriate clothing, and wearable technologies can mitigate heat and cold stress. Future directions should focus on integrating real-time environmental monitoring with individualized training adaptations. Interdisciplinary and cross-disciplinary collaboration along with athlete education, will be essential to enhance preparedness and resilience in a changing climate. Continuous research is needed to refine climate-smart strategies and ensure safe, effective participation in football under variable weather conditions.

Λέξεις ευρετηρίου: Αθλητική απόδοση, Έκθεση στο κρύο, Θερμικό φορτίο, Κλιματική αλλαγή, Ποδόσφαιρο

ΠΕΡΙΛΗΨΗ

Στην εποχή της κλιματικής αλλαγής: Έξυπνες στρατηγικές για υψηλή ποδοσφαιρική απόδοση

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Η κλιματική αλλαγή εισάγει σημαντικές και αυξανόμενες προκλήσεις για τα υπαίθρια αθλήματα, με το ποδόσφαιρο να αποτελεί ένα ιδιαίτερα ευάλωτο παράδειγμα, καθώς οι αθλητές εκτίθενται συστηματικά σε ακραίες περιβαλλοντικές συνθήκες. Οι υψηλές και χαμηλές θερμοκρασίες λειτουργούν ως στρεσογόνοι περιβαλλοντικοί παράγοντες, ενεργοποιώντας νευροενδοκρινικούς και μεταβολικούς μηχανισμούς διατήρησης της ομοιόστασης. Η παρατεταμένη έκθεση σε θερμικό φορτίο μπορεί να διαταράξει την καρδιοαναπνευστική και θερμορρυθμιστική λειτουργία, επηρεάζοντας αρνητικά τη διαδικασία αποκατάστασης και αυξάνοντας τον κίνδυνο μυοσκελετικών τραυματισμών. Συγκεκριμένα, η υπερθερμία συνδέεται με αφυδάτωση, ηλεκτρολυτικές διαταραχές και μειωμένη αιμάτωση των μυών, ενώ το ψύχος επηρεάζει δυσμενώς τον νευρομυϊκό συντονισμό, τη μηχανική απόδοση και την ιδιοδεκτικότητα, αυξάνοντας έτσι τη συχνότητα ατυχημάτων και τραυματισμών. Αντισταθμιστικές παρεμβάσεις περιλαμβάνουν την προληπτική ενυδάτωση, τα τακτικά διαλείμματα για δροσισμό, τη χρήση διαπνεόντων ενδυμάτων, καθώς και την εργοφυσιολογική προσαρμογή των αθλητών στις εκάστοτε κλιματικές συνθήκες. Επί πλέον, η ενσωμάτωση φορητών τεχνολογιών, όπως θερμικοί αισθητήρες, συστήματα GPS και μικροκλιματικοί δείκτες, επιτρέπει την ακριβέστερη και εξατομικευμένη παρακολούθηση της φυσιολογικής καταπόνησης και της θερμικής επιβάρυνσης. Για την προστασία της αθλητικής υγείας και την ενίσχυση της απόδοσης σε ένα περιβάλλον με διαρκώς μεταβαλλόμενο κλίμα απαιτείται μια ολιστική, προληπτική και διεπιστημονική προσέγγιση, που να ενσωματώνει γνώσεις από την Αθλητιατρική, το περιβάλλον και την τεχνολογία.

References

1. PERKINS-KIRKPATRICK SE, LEWIS SC. Increasing trends in regional heatwaves. *Nat Commun* 2020, 11:3357
2. CHRISTIDIS N, STOTT PA. The extremely cold start of the spring of 2018 in the United Kingdom. *Bull Am Meteorol Soc* 2020, 101:S15–S19
3. PÉRIARD JD, EIJSVOGELS TMH, DAANEN HAM. Exercise under heat stress: Thermoregulation, hydration, performance implications, and mitigation strategies. *Physiol Rev* 2021, 101:1873–1979
4. AMERICAN COLLEGE OF SPORTS MEDICINE; SAWKA MN, BURKE LM, EICHNER ER, MAUGHAN RJ, MONTAIN SJ ET AL. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc* 2007, 39:377–390
5. AMERICAN COLLEGE OF SPORTS MEDICINE; ARMSTRONG LE, CASA DJ, MILLARD-STAFFORD M, MORAN DS, PYNE SW ET AL. American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Med Sci Sports Exerc* 2007, 39:556–572
6. CASA DJ, ARMSTRONG LE, HILLMAN SK, MONTAIN, SJ, REIFF RV, RICH BSE ET AL. National athletic trainers' association position statement: Fluid replacement for athletes. *J Athl Train* 2000, 35:212–224
7. RACINAIS S, ALONSO JM, COUTTS AJ, FLOURIS AD, GIRARD O, GONZÁLEZ-ALONSO J ET AL. Consensus recommendations on training and competing in the heat. *Scand J Med Sci Sports* 2015, 25(Suppl 1):6–19
8. LEE JKW, TAN B, KINGMA BRM, HAMAN F, EPSTEIN Y. Biomarkers for warfighter safety and performance in hot and cold environments. *J Sci Med Sport* 2023, 26(Suppl 1):S71–S78
9. RACINAIS S, COCKING S, PÉRIARD JD. Sports and environmental temperature: From warming-up to heating-up. *Temperature (Austin)* 2017, 4:227–257

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