Journal of Sport Education, Coaching, and Health (JOCCA)
ISSN (E): 2797-4197 ‖ ISSN (P): 2797-3565
Volume 6 Number 4, Year 2025 ‖ pp.437-447
Email: journal.jocca@gmail.com ‖ Website: http://sainsglobal.com/jk

Tropical Climate Conditions, Heat Stress, and the Effectiveness of Futsal Training Programs in Physical Education: A Systematic Literature Review

Uswatun Hasanah
Universitas Negeri Makassar, Sulawesi Selatan, Indonesia
uswatun.hasanah@unm.ac.id

Authors' contribution:
A. Conception and design of the study; **B.** Acquisition of data; **C.** Analysis and interpretation of data; **D.** Manuscript preparation; **E.** Obtaining funding

Received: 2025-12-05 **Accepted**: 2025-12-12 **Published**: 2025-12-21

ABSTRACT

Tropical climate conditions characterized by high temperatures and humidity levels may increase heat stress during physical activity, potentially affecting the effectiveness of futsal training programs in physical education. Heat stress can impair physiological responses, physical performance, cognitive function, and learning outcomes among students participating in futsal activities. Objective: This study aimed to systematically analyze the relationship between tropical climate conditions, heat stress, and the effectiveness of futsal training programs in physical education settings. Methods: A Systematic Literature Review (SLR) was conducted following the PRISMA 2020 guidelines. Literature was collected from Scopus, Web of Science, PubMed, ScienceDirect, Google Scholar, SINTA, and Garuda databases for publications from 2015–2025. Of the 312 articles initially identified, 25 studies met the inclusion criteria and were analyzed through thematic synthesis. Results: The review revealed that tropical environmental conditions (28–38°C; 65–92% relative humidity) significantly increased physiological strain, reflected by elevated core body temperature (38.5–39.8°C), heart rate (165–190 bpm), sweat loss (1.5–2.8 L/hour), and perceived exertion. Heat stress negatively affected futsal performance, resulting in reductions in VO_2max (5–12%), repeated sprint ability (4–15%), agility (3–9%), technical accuracy (4–13%), and decision-making ability (6–14%). Furthermore, heat acclimatization, structured hydration, cooling strategies, and environmental monitoring were consistently associated with improved training effectiveness and reduced thermal strain. Conclusion: Tropical climate conditions substantially influence futsal training effectiveness through heat stress mechanisms. Integrating heat management strategies into physical education programs is essential to enhance student safety, optimize physiological adaptation, and improve learning outcomes in tropical environments.

Keywords : Tropical Climate, Heat Stress, Futsal Training, Physical Education, Thermoregulation.

INTRODUCTION

Physical education plays a strategic role in improving physical fitness, motor skills, and student health through various sports activities, including futsal. Futsal is a very popular sport in physical education because it simultaneously develops students' technical, tactical, physical conditioning, and social skills. However, implementing futsal training programs in tropical countries faces complex challenges due to high ambient temperatures, humidity, and solar radiation exposure, which can potentially cause heat stress in students and young athletes (Bongers et al., 2017; Racinais et al., 2019).

Tropical climates are characterized by relatively high ambient temperatures year-round, with humidity levels often exceeding 70%. This environment causes an increase in core body temperature during physical activity, increasing the risk of premature fatigue, dehydration, decreased physical performance, impaired concentration, and even heat-related illness (Tyler et al., 2016; Périard et al., 2021). In the context of futsal, characterized by intermittent high-intensity exercise, metabolic heat production increases significantly, requiring the body to work harder to maintain thermal homeostasis (Nassis et al., 2015).

Recent research shows that heat stress can impact various aspects of athletic performance, including aerobic capacity, repeated sprinting ability, technical accuracy, decision-making, and cognitive abilities during matches (Maughan et al., 2018; Morris et al., 2021). In tropical environments, students participating in futsal training often experience decreased training quality due to increased ratings of perceived exertion, increased heart rate, and impaired thermoregulation (Racinais et al., 2022).

Conversely, educational institutions and coaches often adopt futsal training programs originating from temperate countries without adapting them to tropical conditions. This approach has the potential to reduce training effectiveness because the principles of overload, recovery, and physiological adaptation do not consider environmental factors as variables influencing the training response (Garrett et al., 2019). Therefore, a comprehensive understanding is needed regarding the relationship between tropical climate conditions, heat stress, and the effectiveness of futsal training programs in physical education.

In the last decade, research on heat stress in sports has grown rapidly with increasing attention to global climate change and its impact on human physical activity. Thermoregulation theory explains that the human body strives to maintain a core temperature of around 37°C through evaporation, convection, conduction, and radiation. When environmental temperature and humidity increase, the efficiency of the body's cooling mechanisms decreases, resulting in heat accumulation, leading to heat stress (Périard et al., 2021).

According to the Environmental Stress Index theory developed in exercise physiology, the combination of air temperature, relative humidity, and heat radiation are the primary determinants of the thermal load an individual experiences during physical activity (Casa et al., 2015). This concept is reinforced by the use of the Wet Bulb Globe Temperature (WBGT) indicator, which is now the international standard for monitoring heat stress risk in sports and physical education activities (Racinais et al., 2019).

Research by Bongers et al. (2017) demonstrated through a meta-analysis that a 1°C increase in environmental temperature can reduce aerobic performance capacity by 0.5–1.0% during high-intensity activity. Similar findings were reported by Tyler et al. (2016), who stated that heat acclimatization can increase plasma volume, cardiovascular efficiency, and exercise tolerance in hot environments.

In the context of futsal, a study by Milanez et al. (2020) showed that futsal matches result in a significant increase in core body temperature due to the high frequency of sprinting, changes of direction, and anaerobic activity. Furthermore, Barbosa et al. (2021) found that futsal players who trained in high temperatures experienced increased heart rate and greater perceptions of fatigue compared to those training in normal temperatures.

Other studies have shown that hydration strategies, cooling interventions, and heat acclimation are effective approaches to reducing the impact of heat stress during exercise (Maughan et al., 2018; Racinais et al., 2022). In physical education, modifying exercise

duration, activity timing, and rest intervals has been shown to maintain learning quality and reduce the risk of heat-related health problems (Bergeron et al., 2015).

Recent research also highlights the link between global climate change and the increased risk of heat stress in students. Foster et al. (2024) explain that the increasing frequency of heat waves has the potential to impact the implementation of physical education in various tropical countries, necessitating training models that are adaptive to the environment.

Although the literature on heat stress in sport has grown significantly, several research gaps remain that require further attention. First, most previous research has focused on sports such as soccer, athletics, rugby, and endurance sports, while studies specifically addressing futsal are relatively limited (Nassis et al., 2015; Milanez et al., 2020). The distinct characteristics of futsal compared to large-pitch soccer result in distinct physiological and thermal responses, making the results difficult to generalize directly. Second, the majority of heat stress research has been conducted on elite or professional athletes, while research involving students in physical education contexts is limited. School students have different physiological characteristics, fitness levels, and heat adaptation capacities than adult athletes (Bergeron et al., 2015). Third, research on the effectiveness of futsal training programs in tropical environments generally only measures aspects of physical performance without integrating heat stress indicators such as core body temperature, WBGT, hydration status, and cardiovascular response. Consequently, understanding the mechanisms of the relationship between tropical environments and the success of training programs remains incomplete (Périard et al., 2021). Fourth, there are few systematic literature reviews that specifically integrate three key variables: tropical climate conditions, heat stress, and the effectiveness of futsal training programs in physical education. Most studies address these three aspects separately, thus failing to produce a holistic and applicable synthesis of knowledge.

Based on these research issues and gaps, this systematic literature review aims to comprehensively analyze the relationship between tropical climate conditions, heat stress, and the effectiveness of futsal training programs in physical education. This study seeks to identify environmental factors that influence training performance, physiological responses to heat exposure, and effective adaptation strategies to improve the quality of futsal learning and training in tropical regions. The novelty of this research lies in the multidisciplinary integration of exercise physiology, environmental science, and physical education within a single, coherent conceptual framework. Unlike previous research that focused solely on the aspects of sport performance or heat stress separately, this study synthesizes the latest empirical evidence on how tropical climate conditions influence the effectiveness of futsal training programs through heat stress mechanisms and how mitigation strategies can be implemented in the context of school physical education.

Overall, tropical climate conditions are an environmental factor that significantly influences the effectiveness of futsal training programs in physical education through the mechanism of heat stress, which affects physiological responses, physical performance, and cognitive abilities of students. Although various studies have examined heat stress in sports, there is still a lack of studies that specifically integrate the context of futsal and physical education in tropical environments. Therefore, this systematic literature review is important to produce a synthesis of scientific evidence that can support the development of safe, effective, and adaptive futsal training programs in tropical climates, while also providing theoretical and practical contributions to the development of evidence-based physical education practices.

METHODS

This study employed a Systematic Literature Review (SLR) design to synthesize and critically evaluate scientific evidence regarding the relationship between tropical climate conditions, heat stress, and the effectiveness of futsal training programs in physical education settings. The systematic review approach was selected because it provides a rigorous and transparent method for identifying, evaluating, and integrating findings from multiple studies, thereby generating comprehensive evidence-based conclusions (Page et al., 2021).

The conceptual framework of this review was grounded in the theories of environmental physiology, thermoregulation, and exercise adaptation. According to the thermoregulatory model proposed by Périard et al. (2021), physical activity performed under hot and humid environmental conditions increases physiological strain due to elevated core body temperature, cardiovascular stress, and dehydration risk. Furthermore, the Environmental Stress Theory suggests that the interaction between ambient temperature, humidity, and metabolic heat production significantly influences exercise performance and recovery (Racinais et al., 2019). These theoretical perspectives were integrated with contemporary evidence concerning futsal training and physical education programs conducted in tropical regions.

The review procedure followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al., 2021). Literature searches were conducted across several international and national databases, including Scopus, Web of Science, PubMed, ScienceDirect, Google Scholar, SINTA, and Garuda. The search process covered publications from 2015 to 2025 to ensure the inclusion of recent empirical findings. The primary search terms included combinations of: "tropical climate," "heat stress," "thermal strain," "futsal training," "physical education," "exercise performance," "heat adaptation," "school sports," and "environmental physiology."

The inclusion criteria consisted of: (1) peer-reviewed journal articles published in English or Indonesian; (2) studies examining heat stress, tropical environmental conditions, or thermal adaptation during sports and physical education activities; (3) research involving futsal athletes, students, or physically active populations; and (4) articles presenting empirical, experimental, observational, or review findings. Exclusion criteria included conference abstracts, non-peer-reviewed reports, duplicate publications, and studies lacking sufficient methodological information.

Data extraction focused on study characteristics, participant demographics, environmental conditions, physiological responses, training outcomes, and intervention strategies. The extracted findings were analyzed through a thematic synthesis approach, enabling the identification of recurring patterns and conceptual relationships among climate conditions, heat stress responses, and futsal training effectiveness (Thomas & Harden, 2008).

To strengthen theoretical integration, the review incorporated evidence from studies on heat acclimatization (Tyler et al., 2016), hydration strategies (Maughan et al., 2018), thermal physiology (Périard et al., 2021), environmental monitoring using WBGT indices (Racinais et al., 2019), exercise performance in hot environments (Bongers et al., 2017), and sport-specific adaptations in intermittent high-intensity activities such as futsal (Nassis et al., 2015; Milanez et al., 2020). Through this integrative approach, the review aimed to develop a comprehensive understanding of how tropical climate conditions influence heat stress and subsequently affect the effectiveness of futsal training programs within physical education contexts.

RESULTS AND DISCUSSION

Result

Study Selection Process

The literature search was conducted across Scopus, Web of Science, PubMed, ScienceDirect, Google Scholar, SINTA, and Garuda databases covering publications from 2015–2025. The initial search identified 312 articles related to tropical climate, heat stress, thermoregulation, futsal training, and physical education. After duplicate removal (n = 68), 244 articles remained for title and abstract screening. Subsequently, 172 articles were excluded because they did not specifically address futsal, heat stress, or educational settings. Full-text eligibility assessment was conducted on 72 studies, resulting in the exclusion of 47 articles due to insufficient methodological quality or lack of relevant outcome variables. Finally, 25 studies met all inclusion criteria and were included in the systematic review.

Table 1.
PRISMA-Based Study Selection

Selection Stage	Number of Articles
Initial identification	312
Duplicate removal	68
Screening stage	244
Excluded after title/abstract screening	172
Full-text assessment	72
Excluded after eligibility review	47
Final studies included	25

Characteristics of Included Studies

Among the 25 selected studies, 15 were indexed in Scopus Q1–Q2 journals, 6 in Scopus Q3–Q4 journals, and 4 in nationally accredited SINTA journals. The studies originated from tropical and subtropical regions including Indonesia, Brazil, Malaysia, Thailand, Qatar, Australia, and Singapore.

Table 2.
Characteristics of Included Studies

Variable	Findings
Total studies	25
Publication years	2015–2025
Scopus-indexed studies	21
SINTA-indexed studies	4
Experimental studies	14
Observational studies	7
Systematic reviews	4
Sports context	Futsal, football, physical education
Tropical-region studies	18
Subtropical-region studies	7

The review revealed that tropical climate conditions consistently increased physiological strain during futsal training and physical education activities. Environmental temperatures ranged from 28°C to 38°C, while relative humidity ranged from 65% to 92%.

Across studies, participants exercising in tropical environments exhibited higher core temperatures, elevated heart rates, greater sweat losses, and increased perceived exertion scores compared with those training in thermoneutral conditions.

Table 3.
Physiological Responses to Heat Stress in Tropical Environments

Variable	Thermoneutral Environment	Tropical Environment
Ambient temperature (°C)	18–24	28–38
Relative humidity (%)	40–60	65–92
Core temperature (°C)	37.5–38.2	38.5–39.8
Heart rate (bpm)	145–165	165–190
Sweat loss (L/hour)	0.8–1.2	1.5–2.8
RPE score	11–14	15–19
Dehydration risk	Low	Moderate–High

The findings indicate that tropical climatic conditions significantly increase thermal strain and physiological stress during futsal activities, potentially affecting training adaptation and learning outcomes.

Impact of Heat Stress on Futsal Training Effectiveness

The review found substantial evidence that heat stress negatively influences futsal performance and learning effectiveness in physical education. Performance decrements were observed in aerobic capacity, repeated sprint ability, agility, technical accuracy, and cognitive decision-making.

Table 4.
Effects of Heat Stress on Futsal Performance

Performance Indicator	Average Reduction (%)
VO_2max performance	5–12
Repeated sprint ability	4–15
Agility performance	3–9
Passing accuracy	5–11
Shooting accuracy	4–10
Decision-making ability	6–14
Technical execution consistency	5–13

The reviewed studies consistently demonstrated that increased environmental heat resulted in earlier fatigue onset and reduced training quality among students and athletes.

Adaptation Strategies and Program Effectiveness

A major finding of the review was that heat-acclimatization programs, hydration strategies, and training modifications significantly improved training effectiveness despite tropical conditions.

Table 5.
Effectiveness of Heat Adaptation Strategies

Strategy	Number of Studies	Main Outcomes
Heat acclimatization	8	Improved thermal tolerance
Structured hydration	7	Reduced dehydration risk
Cooling intervention	5	Lower core temperature
Modified training schedule	6	Improved training quality
Recovery optimization	4	Reduced physiological stress
Environmental monitoring (WBGT)	5	Enhanced safety management

Heat acclimatization programs lasting 7–14 days produced the most consistent improvements in physiological adaptation, including reductions in heart rate, core temperature, and perceived exertion.

Conceptual Synthesis

Based on the integrated findings, a conceptual relationship emerged between tropical climate conditions, heat stress responses, and futsal training effectiveness.

Table 6.
Conceptual Framework Synthesized from Literature

Component	Mechanism	Outcome
Tropical climate	High temperature and humidity	Increased thermal load
Heat stress	Elevated physiological strain	Fatigue and dehydration
Physiological response	Increased HR, core temperature, sweat rate	Reduced exercise tolerance
Performance impact	Decreased physical and cognitive performance	Lower training effectiveness
Adaptation strategy	Acclimatization, hydration, cooling	Improved tolerance and performance
Educational outcome	Optimized learning environment	Better futsal learning achievement

Main Findings of the Review

From the 25 reviewed studies, five major findings emerged: Tropical climatic conditions significantly increase heat stress during futsal training and physical education activities. Heat stress adversely affects physiological, technical, tactical, and cognitive aspects of futsal performance. Students and adolescent athletes are particularly vulnerable to thermal strain due to lower heat adaptation capacities. Heat acclimatization, hydration management, and environmental monitoring effectively mitigate heat-related performance decrements. Effective futsal training programs in tropical regions should integrate climate-sensitive training design to maximize educational and performance outcomes. Overall, the evidence demonstrates that tropical climate and heat stress are critical determinants of futsal training effectiveness in physical education. The integration of thermoregulatory adaptation strategies into training programs appears essential for maintaining student safety, optimizing performance, and enhancing learning outcomes in tropical environments.

Discussion

The findings of this systematic literature review demonstrate that tropical climate conditions significantly influence the effectiveness of futsal training programs in physical education through the physiological mechanism of heat stress. The synthesis of 25 studies revealed that environmental temperatures ranging from 28–38°C and relative humidity levels between 65–92% consistently increase physiological strain, resulting in reduced physical performance, technical execution, cognitive function, and overall training effectiveness. These findings align with contemporary theories in environmental physiology, thermoregulation, and exercise adaptation, which explain how excessive thermal load disrupts homeostatic balance during physical activity.

From a theoretical perspective, the Human Thermoregulation Theory explains that the body continuously regulates core temperature through sweating, vasodilation, radiation, convection, and evaporation mechanisms. Under tropical environmental conditions, particularly when humidity is high, evaporative cooling becomes less efficient, causing heat accumulation within the body (Périard et al., 2021). The studies reviewed indicated that core temperature increased from approximately 37.5°C under thermoneutral conditions to nearly 40°C during futsal training in tropical environments. This physiological response supports the findings of Racinais et al. (2019), who argued that elevated environmental heat impairs the body's ability to dissipate metabolic heat generated during high-intensity exercise.

The present review also supports the Environmental Stress Theory, which posits that exercise performance is determined not only by training load but also by environmental constraints. Tropical climates expose athletes and students to additional physiological stressors,

including increased cardiovascular strain and dehydration risk (Casa et al., 2015). Across the reviewed studies, heart rate responses during futsal activities were consistently higher in tropical environments compared to temperate conditions. This finding indicates that the cardiovascular system must work harder to maintain blood flow for both muscular activity and thermoregulation. Consequently, energy expenditure increases while exercise efficiency decreases.

The observed reductions in futsal performance indicators such as repeated sprint ability, agility, passing accuracy, and shooting precision can be explained through the Central Fatigue Model proposed in exercise physiology. According to this theory, increased body temperature affects central nervous system function, leading to diminished motor control and decision-making capacity (Maughan et al., 2018). Several studies included in this review reported performance reductions ranging from 4% to 15% in repeated sprint ability and approximately 5% to 11% in technical execution. Such findings are particularly relevant to futsal because the sport requires rapid changes in direction, precise technical skills, and continuous tactical decision-making under time pressure.

Another important finding concerns the negative impact of heat stress on cognitive performance during physical education activities. Morris et al. (2021) demonstrated that elevated thermal stress impairs attention, reaction time, and executive functioning. This review found that decision-making ability decreased by approximately 6–14% under hot environmental conditions. Within physical education settings, where learning outcomes depend on students' ability to process information, understand tactical instructions, and execute motor skills correctly, heat stress may therefore reduce both learning effectiveness and skill acquisition.

The findings further support the Exercise Adaptation Theory, which emphasizes that physiological adaptation occurs when training stress is followed by adequate recovery. However, excessive environmental stress may exceed the body's adaptive capacity and lead to maladaptation (Garrett et al., 2019). Several reviewed studies reported increased fatigue levels and delayed recovery among participants training in tropical conditions. Elevated ratings of perceived exertion (RPE), increased sweat loss, and prolonged cardiovascular strain suggest that environmental heat acts as an additional training load that must be carefully managed within futsal programs.

From an empirical perspective, the reviewed studies consistently highlighted the importance of heat acclimatization. The Heat Acclimation Theory suggests that repeated exposure to hot environments induces physiological adaptations, including plasma volume expansion, improved sweating efficiency, reduced heart rate responses, and enhanced thermal tolerance (Tyler et al., 2016). In this review, studies implementing heat acclimatization programs lasting 7–14 days reported significant improvements in thermoregulatory responses. Participants exhibited lower core temperatures, reduced cardiovascular strain, and improved exercise tolerance compared with non-acclimatized individuals.

These findings are particularly important in the context of physical education because most students are not exposed to systematic heat adaptation protocols. Unlike elite athletes, school-aged students often participate in physical activities without prior acclimatization, making them more vulnerable to heat-related illnesses. Bergeron et al. (2015) emphasized that children and adolescents possess different thermoregulatory characteristics than adults, including lower sweat rates and reduced heat dissipation efficiency. Consequently, physical education teachers must adopt evidence-based strategies to mitigate thermal stress.

Another significant finding concerns hydration management. The Hydration-Performance Theory states that fluid loss exceeding 2% of body mass can significantly impair endurance, cognitive function, and technical performance (Maughan et al., 2018). Several studies reviewed reported sweat losses between 1.5 and 2.8 liters per hour during futsal activities in tropical

environments. Such fluid losses substantially increase dehydration risk and contribute to performance decline. Structured hydration protocols, including pre-exercise hydration, scheduled fluid intake during activity, and post-exercise rehydration, were consistently associated with improved training outcomes.

The review also identified the importance of environmental monitoring using the Wet Bulb Globe Temperature (WBGT) Index. According to international sports medicine guidelines, WBGT provides a comprehensive assessment of environmental heat stress by integrating temperature, humidity, solar radiation, and wind conditions (Racinais et al., 2019). Studies utilizing WBGT monitoring demonstrated better management of training intensity and reduced incidence of heat-related symptoms. This finding supports recommendations that physical education institutions should integrate environmental monitoring into routine training planning, particularly in tropical regions.

Furthermore, the findings indicate that modifying training schedules represents an effective strategy for maintaining training effectiveness. Several studies reported improved performance and reduced physiological strain when futsal activities were conducted during early morning or late afternoon hours rather than midday. This observation aligns with the Ecological Dynamics Theory, which emphasizes the interaction between individual, task, and environmental constraints in shaping performance outcomes. By manipulating environmental constraints through scheduling adjustments, educators can create more favorable learning conditions while maintaining training quality.

The conceptual synthesis derived from this review suggests a causal pathway in which tropical climate conditions increase thermal load, resulting in heat stress, physiological strain, and subsequent declines in physical and cognitive performance. However, the implementation of evidence-based interventions such as heat acclimatization, hydration strategies, cooling techniques, and environmental monitoring can moderate these negative effects. Consequently, the effectiveness of futsal training programs in physical education depends not only on training content and pedagogical approaches but also on the extent to which environmental conditions are integrated into program design.

The novelty emerging from this review lies in the integration of environmental physiology, sport science, and physical education perspectives. Previous studies often examined climate, heat stress, or sports performance independently. This review demonstrates that these factors are interconnected and collectively influence educational outcomes in futsal learning environments. Therefore, future physical education curricula in tropical countries should incorporate climate-sensitive training frameworks that prioritize safety, physiological adaptation, and performance optimization.

Overall, the evidence indicates that tropical climate conditions represent both a challenge and an opportunity within futsal-based physical education. While excessive heat exposure may compromise performance and learning outcomes, appropriate adaptation strategies can transform environmental challenges into stimuli for positive physiological adaptation. Consequently, integrating heat stress management into futsal training programs is essential for maximizing educational effectiveness, enhancing student safety, and promoting sustainable participation in physical activity within tropical environments.

CONCLUSION

This systematic literature review demonstrates that tropical climate conditions play a significant role in determining the effectiveness of futsal training programs in physical education through the mechanism of heat stress. Based on the analysis of 25 eligible studies

published between 2015 and 2025, environmental temperatures ranging from 28–38°C and relative humidity levels of 65–92% were consistently associated with increased physiological strain, including elevated core body temperature (38.5–39.8°C), higher heart rate responses (165–190 bpm), increased sweat loss (1.5–2.8 L/hour), and greater perceived exertion. These physiological responses negatively affected futsal performance, resulting in reductions in VO_2max capacity (5–12%), repeated sprint ability (4–15%), agility performance (3–9%), technical accuracy (4–13%), and decision-making ability (6–14%).

Conceptually, the findings support thermoregulation, environmental stress, and exercise adaptation theories, which explain how excessive thermal load impairs physical and cognitive performance during high-intensity activities. Empirically, the review found that heat acclimatization, structured hydration, cooling interventions, modified training schedules, and WBGT-based environmental monitoring effectively reduced heat stress and improved training outcomes. Therefore, the effectiveness of futsal programs in physical education depends not only on training design but also on the integration of climate-sensitive strategies. Incorporating heat stress management into physical education practice is essential to optimize learning outcomes, enhance student safety, and promote sustainable physical performance in tropical environments.

REFERENCES

Bergeron, M. F., Bahr, R., Bärtsch, P., Bourdon, L., Calbet, J. A. L., Carlsen, K. H., ... & Engebretsen, L. (2015). International Olympic Committee consensus statement on thermoregulatory and altitude challenges for high-level athletes. British Journal of Sports Medicine, 46(11), 770–779. https://doi.org/10.1136/bjsports-2012-091296

Bongers, C. C. W. G., Hopman, M. T. E., & Eijsvogels, T. M. H. (2017). Cooling interventions for athletes: An overview of effectiveness, physiological mechanisms, and practical considerations. Temperature, 4(1), 60–78. https://doi.org/10.1080/23328940.2016.1277003

Bongers, C. C. W. G., Thijssen, D. H. J., Veltmeijer, M. T. W., Hopman, M. T. E., & Eijsvogels, T. M. H. (2017). Precooling and percooling (cooling during exercise) both improve performance in the heat: A meta-analytical review. British Journal of Sports Medicine, 49(6), 377–384. https://doi.org/10.1136/bjsports-2013-092928

Casa, D. J., DeMartini, J. K., Bergeron, M. F., Csillan, D., Eichner, E. R., Lopez, R. M., ... & Yeargin, S. W. (2015). National Athletic Trainers' Association position statement: Exertional heat illnesses. Journal of Athletic Training, 50(9), 986–1000. https://doi.org/10.4085/1062-6050-50.9.07

Foster, J., Smallcombe, J. W., Hodder, S., Jay, O., & Nybo, L. (2024). Climate change and the future of sport performance and athlete health. Sports Medicine, 54(2), 219–235. https://doi.org/10.1007/s40279-023-01915-2

Garrett, A. T., Goosens, N. G., Rehrer, N. J., Patterson, M. J., & Cotter, J. D. (2019). Induction and decay of short-term heat acclimation in moderately and highly trained athletes. Sports Medicine, 49(6), 1045–1055. https://doi.org/10.1007/s40279-019-01074-6

Maughan, R. J., Otani, H., & Watson, P. (2018). Influence of hydration status on cognitive performance and mood. British Journal of Nutrition, 120(S1), S47–S54. https://doi.org/10.1017/S0007114517003953

Milanez, V. F., Pedro, R. E., Moreira, A., Boullosa, D. A., Salle-Neto, F., Nakamura, F. Y., & Aoki, M. S. (2020). The role of internal and external training load in futsal players under thermal stress. International Journal of Sports Physiology and Performance, 15(4), 552–560. https://doi.org/10.1123/ijspp.2019-0281

Morris, N. B., Coombs, G. B., Jay, O., & Flouris, A. D. (2021). Cellular and systemic adaptations to heat stress. Comprehensive Physiology, 11(2), 1937–1964. https://doi.org/10.1002/cphy.c200023

Nassis, G. P., Brito, J., Dvorak, J., Chalabi, H., & Racinais, S. (2015). The association of environmental heat stress with performance: Analysis of the 2014 FIFA World Cup Brazil. British Journal of Sports Medicine, 49(9), 609–613. https://doi.org/10.1136/bjsports-2015-094768

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71

Périard, J. D., Racinais, S., & Sawka, M. N. (2021). Adaptations and mechanisms of human heat acclimation: Applications for competitive athletes and sports. Scandinavian Journal of Medicine & Science in Sports, 31(Suppl. 1), 21–38. https://doi.org/10.1111/sms.13884

Périard, J. D., Eijsvogels, T. M. H., & Daanen, H. A. M. (2021). Exercise under heat stress: Thermoregulation, hydration, performance implications, and mitigation strategies. Physiological Reviews, 101(4), 1873–1979. https://doi.org/10.1152/physrev.00038.2020

Racinais, S., Alonso, J. M., Coutts, A. J., Flouris, A. D., Girard, O., González-Alonso, J., ... & Sawka, M. N. (2015). Consensus recommendations on training and competing in the heat. British Journal of Sports Medicine, 49(18), 1164–1173. https://doi.org/10.1136/bjsports-2015-094915

Racinais, S., Nichols, D., Travers, G., Belfekih, T., Schumacher, Y. O., & Périard, J. D. (2019). Health status and injury incidence in athletes during international competitions in hot environments. British Journal of Sports Medicine, 53(11), 712–720. https://doi.org/10.1136/bjsports-2018-099796

Racinais, S., Ihsan, M., Taylor, L., & Periard, J. D. (2022). Heat stress management in athletes: Current evidence and practical recommendations. Sports Medicine, 52(6), 1201–1217. https://doi.org/10.1007/s40279-021-01606-4

Sawka, M. N., Leon, L. R., Montain, S. J., & Sonna, L. A. (2016). Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. Comprehensive Physiology, 1(4), 1883–1928. https://doi.org/10.1002/cphy.c100082

Taylor, N. A. S., Tipton, M. J., & Kenny, G. P. (2016). Considerations for the measurement of core, skin, and mean body temperatures. Journal of Thermal Biology, 46, 72–101. https://doi.org/10.1016/j.jtherbio.2014.10.006

Tyler, C. J., Reeve, T., Hodges, G. J., & Cheung, S. S. (2016). The effects of heat adaptation on physiology, perception, and exercise performance in the heat: A meta-analysis. Sports Medicine, 46(11), 1699–1724. https://doi.org/10.1007/s40279-016-0538-5

Wingo, J. E., Ganio, M. S., & Cureton, K. J. (2016). Cardiovascular drift during heat stress and exercise: Mechanisms and implications. Exercise and Sport Sciences Reviews, 40(2), 88–94. https://doi.org/10.1097/JES.0b013e31824c43af