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DEPARTMENT OF PHYSICAL EDUCATION AND SPORT SCIENCES

AND

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TITLE

The Effects of Adverse Environmental Factors on Endurance Races

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CONTENTS

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THE EFFECTS OF ADVERSE ENVIRONMENTAL FACTORS ON ENDURANCE RACES

ABSTRACT

Introduction: This study aimed to assess changes in the core and skin temperatures of volunteers during half-marathon (21 km) races under real conditions and to evaluate the effect of heat stress on the performance and physiology of the participants. Additionally, to test whether the core and skin temperatures of these athletes could be predicted accurately, we used the FAME Lab Predicted Heat Strain software (PHS). **Methods:** 16 endurance athletes participated in this study (age: 37-71 yr, height: 172.5±12.5 cm, weight: 70±20 kg). Before and after the race, the athletes' hydration status was assessed via urine specific gravity. During the race, heart rate, skin temperature (4 sensors), and body core temperature (pill capsule) were recorded. Also, a portable weather station was used to collect ambient temperature, humidity, wind speed, and solar radiation. After the race, volunteers completed a 20-item questionnaire requesting their subjective assessment of the environmental conditions of the race. **Results:** With the use of paired samples t-test and the correlation test from SPSS, we found that the temperature values of Core in Real time (38.27± 1.06) and in PHS(38.24± 1.06) are very close and $p>0.05$. On the other hand, the temperature values of Skin in Real time (29.6± 3.21) and in PHS (35± 3.21) are not close and $p<0.05$. Also, the results from the use of bias-corrected calculations revealed that there is no significant effect size difference on the core temperature between real time and software PHS (0.04), but on skin temperature between real time and software PHS (2.51), there is a significant effect size difference. **Conclusion:** The prediction of volunteer's temperature on these two half marathons in a hot environment showed that it is hard to foresee some results, such as skin temperature and we should to find ways and better solutions to improve software and applications such as PHS, so we have a better understanding of what to expect in extreme environments.

KEY WORDS:
Skin temperature, Core temperature, heat stress, endurance races.

ΠΕΡΙΛΗΨΗ

Εισαγωγή: Ο στόχος αυτής της μελέτης ήταν να αξιολογήσει τις αλλαγές στη θερμοκρασία του πυρήνα και του δέρματος των εθελοντών κατά τη διάρκεια αγώνων ημιμαραθωνίου (21 χιλιόμετρα) υπό πραγματικές συνθήκες και να αξιολογήσει την επίδραση του θερμικού στρες στην απόδοση και τη φυσιολογία των συμμετεχόντων. Επιπλέον, για να ελέγξουμε εάν οι θερμοκρασίες του πυρήνα και του δέρματος αυτών των αθλητών μπορούσαν να προβλεφθούν με ακρίβεια, χρησιμοποιήσαμε το λογισμικό FAME Lab Predicted Heat Strain (PHS).**Μέθοδοι:** 16 αθλητές αντοχής συμμετείχαν σε αυτή τη μελέτη (ηλικία: 37-71 ετών, ύψος: 172,5±12,5 cm, βάρος: 70±20 kg). Πριν και μετά τον αγώνα, η κατάσταση ενυδάτωσης των αθλητών αξιολογήθηκε μέσω του ειδικού βάρους των ούρων. Κατά τη διάρκεια του αγώνα, καταγράφηκαν καρδιακοί παλμοί, θερμοκρασία δέρματος (4 αισθητήρες) και θερμοκρασία του πυρήνα του σώματος (κάψουλα χαπιού). Επίσης, ένας φορητός μετεωρολογικός σταθμός χρησιμοποιήθηκε για τη συλλογή της θερμοκρασίας περιβάλλοντος, της υγρασίας, της ταχύτητας του ανέμου και της ηλιακής ακτινοβολίας. Μετά τον αγώνα, οι εθελοντές συμπλήρωσαν ένα ερωτηματολόγιο 20 θεμάτων ζητώντας την υποκειμενική τους αξιολόγηση των περιβαλλοντικών συνθηκών του αγώνα. **Αποτελέσματα:** Με τη χρήση ζευγών δειγμάτων t-test και του τεστ συσχέτισης από το SPSS, βρήκαμε ότι οι τιμές θερμοκρασίας του πυρήνα σε πραγματικό χρόνο (38,27± 1,06) και στο PHS (38,24± 1,06) είναι πολύ κοντινές και $p>0.05$. Από την άλλη, οι τιμές θερμοκρασίας του δέρματος σε πραγματικό χρόνο (29,6± 3,21) και στο PHS (35± 3,21) δεν είναι κοντινές και $p<0.05$. Επίσης, τα αποτελέσματα από τη χρήση υπολογισμών με διορθωμένη προκατάληψη αποκάλυψαν ότι δεν υπάρχει σημαντική διαφορά μεγέθους επίδρασης στη θερμοκρασία του πυρήνα μεταξύ πραγματικού χρόνου και PHS λογισμικού (0,04), αλλά στη θερμοκρασία δέρματος μεταξύ πραγματικού χρόνου και PHS λογισμικού (2,51), υπάρχει σημαντική διαφορά μεγέθους επίδρασης. **Συμπέρασμα:** Η πρόβλεψη της θερμοκρασίας του εθελοντή σε αυτούς τους δύο ημιμαραθώνιους σε θερμό περιβάλλον έδειξε ότι είναι δύσκολο να προβλεφθεί η θερμοκρασία του δέρματος απ΄ ότι της θερμοκρασίας του πυρήνα και γι’ αυτό χρειάζεται να βρούμε τρόπους για την καλύτερη βελτίωση πρόβλεψης του λογισμικού(PHS).

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Θερμοκρασία δέρματος, θερμοκρασία πυρήνα, θερμική καταπόνηση, αγώνες αντοχής.

ΥΠΕΥΘΥΝΗ ΔΗΛΩΣΗ

Ο κάτωθι υπογεγραμμένος Νίκος Αθανασιάδης, μεταπτυχιακός φοιτητής της σχολής Ιατρικής και Επιστήμης Φυσικής Αγωγής και Αθλητισμού του προγράμματος Μεταπτυχιακών Σπουδών «Άσκηση, Εργοσπιρομετρία και Αποκατάσταση Π.Θ.» δηλώνω υπεύθυνα ότι αποδέχομαι τους παρακάτω όρους που αφορούν:

α) στα πνευματικά δικαιώματα της Μεταπτυχιακής Διπλωματικής Εργασίας (ΜΔΕ) μου με τίτλο: «**The effects of adverse environmental factors on endurance races**».

β) στη διαχείριση των ερευνητικών δεδομένων που θα συλλέξω στην πορεία εκπόνησής της:

Τα πνευματικά δικαιώματα του τόμου της μεταπτυχιακής ή διδακτορικής διατριβής που θα προκύψει θα ανήκουν σε μένα. Θα ακολουθήσω τις οδηγίες συγγραφής, εκτύπωσης και κατάθεσης αντιτύπων της διατριβής στα ανάλογα αποθετήρια (σε έντυπη ή/και σε ηλεκτρονική μορφή).

Η διαχείριση των δεδομένων της διατριβής ανήκει από κοινού σε εμένα και στον κύριο επιβλέποντα καθηγητή.

Οποιαδήποτε επιστημονική δημοσίευση ή ανακοίνωση (αναρτημένη ή προφορική), ή αναφορά που προέρχεται από το υλικό/δεδομένα της εργασίας αυτής θα γίνεται με συγγραφείς εμένα τον ίδιο, τον κύριο επιβλέποντα ή/και άλλους ερευνητές (πχ μέλη της τριμελούς συμβουλευτικής επιτροπής, συνεργάτες κλπ), ανάλογα με τη συμβολή τους στην έρευνα και στη συγγραφή των ερευνητικών εργασιών. Η σειρά των ονομάτων στις επιστημονικές δημοσιεύσεις ή επιστημονικές ανακοινώσεις θα αποφασίζεται από κοινού από εμένα και τον κύριο επιβλέποντα της εργασίας, πριν αρχίσει η εκπόνησή της.

Η απόφαση αυτή θα πιστοποιηθεί εγγράφως μεταξύ εμού και του κύριου επιβλέποντος.

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23/06/2023

Ο δηλών

Νίκος Αθανασιάδης

CATALOG OF FIGURES

CHAPTER 1: INTRODUCTION

DEFINITION OF HALF-MARATHON

An endurance race of 21.0975 km is exactly half the distance of a complete marathon (42 km) (World Athletics, 2022). Half marathons are very popular race events, because many race tournaments are occurring globally each year (World Athletics, 2022). The time finish of the half marathon is defined on the time of the athletes (World Athletics, 2022).The half marathon is excluded from in any Olympic Games or World athletic tournaments but plays a major role as an event for endurance athletes for more than 70 years (World Athletics, 2022).

The development of long-distance running, gave to the athletic organizers to look for an alternative race rather than the basic marathon distance and that is how the half marathon started (World Athletics, 2022).

HEAT EXPOSURE

Heat is a health concern that strains the human physiology either through exercise or the environment, which frequently results in the loss of aerobic fitness and work against other extreme environmental conditions (Campbell et., 2022).

Extremely high temperatures can worsen preexisting medical issues, resulting in disease and death (Liu, J. et., 2022). All persons are at danger from heat-related mortality and morbidity, but older people and those with compromised cardiovascular health are particularly at risk (Liu, J. et., 2022).

The background incidence of cardiovascular disease is anticipated to significantly rise because of population expansion and aging, and so are the likely negative effects of ambient heat exposure, particularly in low and middle income countries (Liu, J. et., 2022).
Impacts will certainly vary depending on population, society, lifestyle, and elements influencing the degree of physiological adaptation in humans (Liu, J. et., 2022). The relationship between heat and cardiovascular disease outcomes and differences in effects based on local surroundings and climates across different climate zones must therefore be better understood (Liu, J. et., 2022).
These findings underline the need to investigate how exposure to ambient heat affects cardiovascular health across a range of climate zones and geographic locations (Liu, J. et., 2022).

AIM

Climate change has significantly altered how humans should live and exercise on our planet, as guidelines are required to provide them with the physical skills necessary to cope with the adverse environmental conditions of tropical climates and train systematically to adapt to those conditions. The effects of heat and heat acclimation are a major issue for human health and precautions and guidelines need to be taken so that the individual can exercise and live a normal life in the environment they live in. Prolonged exercise in the heat reduces muscle endurance and generally damages the muscles when they are activated when they contract.
My research aimed to evaluate the performance and physiology of adult volunteers during prolonged exercise in heat. It is important to write a paper on exercise endurance in a hot environment, as it will provide a general and concise presentation about exercise in a hot environment.

The temperature of the environment changes rapidly and therefore the assessment of the health and performance of humans at high temperatures is critical.

Null Hypothesis

- Temperature values of Core in Real time and in PHS are not close and $p<0.05$.
- Temperature values of Skin in Real time and in PHS are close and $p>0.05$.

Alternative Hypothesis

- Temperature values of Core in Real time and in PHS are very close and $p>0.05$.
- Temperature values of Skin in Real time and in PHS are not close and $p<0.05$.

CHAPTER 2: LITERATURE REVIEW

1) Thermoregulation and Global Climate

Because of climate change, the global average temperatures have risen dramatically (El Khayat et., 2022). Since pre-industrial times, they have risen by approximately 1.1°C on average (El Khayat et., 2022). Furthermore, heat waves have become longer, more frequent, and more severe throughout the planet (El Khayat et., 2022). Nineteen of the twenty warmest years on record have occurred since 2000(El Khayat et., 2022). The great majority of the world's areas have had at least one additional day of heat wave per decade between 1950 and 2017 (El Khayat et., 2022). Temperatures are expected to increase in the future, and extreme heat events will become more common, longer, and intense (El Khayat et., 2022). Heat stress is expected to affect four times as many individuals as those already affected by extreme heat by the end of the century (El Khayat et., 2022). Many negative health effects can result from exposure to high temperatures (El Khayat et., 2022).

An organism's capacity to maintain a predetermined body temperature in different external environments is referred to as thermoregulation (Julien D. Périard et al., 2021). A study of heat balance, or the relationship between heat gain and loss, will also include an analysis of the elements of the human thermal environment (Julien D. Périard et al., 2021). It is important to note that task-dependent variables such as metabolic rate and clothing, environmental variables such as temperature, humidity, wind speed and solar radiation, as well as personal variables such as age, gender, body mass, morphology, and aerobic fitness are included among these variables (Julien D. Périard et al., 2021).). It is also crucial to emphasize the importance of the Earth-

Atmosphere Energy Balance, or the balance between the Sun's Incoming Energy and the Earth's Outgoing Energy, to global climate (National Weather Service, 2022). Shortwave light and ultraviolet radiation are two types of solar energy emitted by the Sun (National Weather Service, 2022). Light that strikes the Earth is reflected back into space by clouds, absorbed by the atmosphere, and absorbed at the Earth's surface (National Weather Service, 2022). A significant contribution to the global energy balance is the absorption of infrared radiation seeking to escape from the Earth and return to space (National Weather Service, 2022). If there was no atmosphere, the absorption of energy at the surface would be greater than if there were none (National Weather Service, 2022). Climate change will cause temperatures to rise in many parts of the world. Global temperatures in 2020 were 1.2 degrees Celsius higher than pre-industrial levels (Physical Activity et., 2022). In many regions, 2020 was the warmest year ever recorded (Physical Activity et., 2022). In accordance to current projections, the average temperature will continue to rise sharply until 2100. (Physical Activity et., 2022). Further, due to climate change, short-to medium-term high air temperatures in the summer will become more frequent, severe, and prolonged (Physical Activity et., 2022). When the ambient temperature rises, the circulatory, pulmonary, and metabolic systems are frequently put under greater strain (Physical Activity et., 2022). Despite being exposed to various external conditions, humans generally maintain a core body temperature of 37°C (Balmain et., 2018). A safe, restricted range of body temperature (between 35 and 39°C) allows metabolic responses to occur at a close to optimal level in the human body (Balmain et., 2018). The thermoregulatory system activates a range of physiological systems to maintain heat balance when humans are subjected to heat stress, which includes high temperatures, exercise endurance, or a combination of both (Balmain et., 2018).

Weather patterns that are affected by climate change make it harder for pollutants to be naturally cleared away by wind and rain, and the severity and spread of wildfires make breathing in smoke more difficult (Parker CL et., 2019).

‘’The average surface temperature of the moon, which has no atmosphere, is -18°C (National Weather Service, 2022). In contrast, the average surface temperature of the Earth is 15°C’’.This heating effect is referred to as the "greenhouse effect" (National Weather Service, 2022). It is possible to experience exercise-related heat stress when exercising in hot or humid weather, or when wearing heavy clothing and/or equipment that regulates body temperature (J. McCubbin et al., 2020). Numerous high-intensity endurance events are regularly held outdoors in such conditions, including 10-kilometer road races, half-marathons, cycling time trials, and ultra-endurance events, such as Ironman World Championships and Marathon des Sables. Team sports, such as soccer and racquet sports, are also regularly held in outdoor environments under such conditions (J. McCubbin et al., 2020).). There are several types of sports that can be played in hot and/or humid indoor environments, including squash and motor racing, where the driver or rider is exposed to temperatures above 45°C while wearing protective gear (J. McCubbin et al., 2020). It is important to note that major sporting events taking place in hot and humid environments, such as the 2020 Summer Olympics in Tokyo, Japan, and the 2019 IAAF World Championships in Doha Qatar, merit special consideration since the conditions present a significant challenge to many competitors and require specific preparation (J. McCubbin et al., 2020)High workout body temperatures result from a continuing imbalance between internal heat production and external heat dissipation at the skin's surface (J.

McCubbin et al., 2020). Because of rapid metabolism, large amounts of heat are created, helping muscle contractions (J. McCubbin et al., 2020). Convection and radiation can both absorb and lose heat at the same time, and sweat evaporation can also release heat (J. McCubbin et al., 2020). Convective heat exchange is influenced by the temperature difference between the skin and air, which is dependent on wind speed (J. McCubbin et al., 2020). Radiant heat exchange is determined by the difference between skin temperature and mean radiant temperature, which on a clear summer day might be 10-15 °C higher than air temperature (J. McCubbin et al., 2020). The absolute humidity difference between the skin and air effects evaporative heat loss, which increases with wind speed (J. McCubbin et al., 2020). Clothes and equipment, depending on their insulation and water vapor permeability, act as a heat loss barrier (J. McCubbin et al., 2020). The neurons that control these reflexes are born in the hypothalamus, a small core part of the brain (J. McCubbin et al., 2020). The hypothalamus receives continuous information about the body's thermal status due to afferent input from thermoreceptors found in deep bodily tissues and the skin's layer (J. McCubbin et al., 2020). As skin temperature rises, elevated core temperatures may cause cutaneous vasodilation to redistribute heat content and promote convective and radiative heat loss (J. McCubbin et al., 2020).If non-evaporative heat loss is insufficient to compensate for the increased rates of heat production caused by cholinergic release, the core temperature rises and eccrine sweat glands activate (J. McCubbin et al,.2020). If the ambient temperature allows sweat evaporation to balance heat generation, the core temperature will rise but normally remain within a healthy range (J. McCubbin et al., 2020). However, as the heat output reaches this limit, people' body temperatures continue to rise, a condition known as uncompensable heat stress (J. McCubbin et al., 2020). In order to regulate the body's temperature, both behavioral thermoregulation and autonomic thermoregulation can be engaged simultaneously (Julien D. Périard et al., 2021). In hot weather, several conscious behavioral adjustments can reduce the body's temperature, such as standing in the shade, drinking cold beverages, spraying water over one's head, and wearing light-colored clothing (Julien D. Périard et al., 2021).It has also been proposed that changes in work rate made while exercising in the heat are behavioral changes that help control body temperature (Julien D. Périard et al., 2021). The demand for autonomic reactions, which are controlled by physiological systems independent of conscious voluntary behavior, is lowered by thermoregulatory behavior (Julien D. Périard et al., 2021). The modulation of vasomotor and sudomotor (sweating) functions in hot situations, as well as metabolic heat generation and vasomotor function in cold conditions, are examples of these reactions (Julien D. Périard et al., 2021). For that the wet-bulb globe temperature is an important tool that can help us deal with heat stress and protect ourselves from heat exposure (Fukuhara et., 2021). The National Weather Service also has a website to measure the heat index, and uses it by asserting four levels from scale one, which is caution, to scale four, which are extreme conditions (Fukuhara et., 2021). On each level, they have a plan on how to protect humanity from adverse environmental factors (Fukuhara et., 2021).

2) Heat Stress in Human Physiology

When a person is unable to maintain homeostasis and subsequently healthy internal body temperatures, heat stress results (Parkes et., 2022).

Hyperthermia is caused by extreme heat stress, and many physiological variables, such as cardiovascular disease, diabetes, and drug usage, enhance the fatality rate (Parkes et., 2022). An individual's capability for adaptation is correlated with their capacity to modify their environment to prevent heat stress (Parkes et., 2022). A combination of physiological, technological, and financial elements makes up adaptive capability (Parkes et., 2022). Richer people have more possibilities to change their surroundings to suit them, and they also have a greater ability for adaptation (Parkes et., 2022). A continuous, prolonged aerobic activity under ambient heat stress is characterized by an aggravated rise in body core temperature, decreased blood flow to muscles, skin, and muscle glycogen, and increased reliance on anaerobic metabolism and muscle glycogen (Periard et al., 2021). Research showed that repeated bouts of aerobic exercise create hyperthermia, which causes heat adaptation even in the absence of external thermal stress (MARTINS et., 2022).

Aerobic performance gradually suffers because of the increased thermal strain brought on by continuous exercise (skin and core body temperatures) (J. McCubbin et al., 2020). This impairment is linked with an increase in cardiovascular strain mediated by thermoregulation, which results in a loss in maximum aerobic capacity and a potential reduction in voluntary drive due to hyperthermia (J. McCubbin et al., 2020). Moreover, due to increased reliance on muscle glycogen and anaerobic metabolism brought on by exertional heat stress, endogenous glycogen reserves during endurance exercise may be prematurely depleted (J. McCubbin et al., 2020). In contrast, an increase in body temperature, particularly in the muscles, increases metabolic and contractile performance, making it easier to perform high-intensity workouts such as running and leaping (J. McCubbin et al., 2020). In hot environments, when repeated sprints approach a point of diminishing returns due to aggravated physiological responses, single sprints may prove more beneficial than repeated sprints (J. McCubbin et al., 2020).

It has noted that some parameters in biological tissue are profoundly affected by temperature, including plasma membrane fluidity and transmembrane transport rates (Matthew N. Cramer et al., 2022). Humans, being homeothermic, keep tissue temperatures essentially constant (Matthew N. Cramer et al., 2022). For the deep body state, including the head and thorax, resting temperatures typically range between 36°C and 38°C (Matthew N. Cramer et al., 2022). Maintaining deep body temperature requires continuous metabolic activity as a heat source and regulation of metabolic heat transportation from deep tissues to the environment (Matthew N. Cramer et al., 2022). During exercise or ambient heat stress, elevated deep body temperatures of 38-40°C are normal and generally well tolerated, particularly by those who have been exposed to heat or who have participated in aerobic training in the past. At temperatures higher than 40°C, there is a greater risk of heat illnesses and heat stroke (Matthew N. Cramer et al., 2022). In the physical sense, "heat stress" is defined as a heat load that tends to raise deep body temperatures and increase the storage of body heat (Matthew N. Cramer et al., 2022). Six characteristics determine the severity of heat stress (Matthew N. Cramer et al., 2022). In most cases, heat is generated as a result of metabolism, especially when physical activity is involved (Matthew N. Cramer et al., 2022). In addition to air temperature, mean radiant temperature, ambient vapor pressure, and air velocity, four climatic elements affect heat loss rates between the skin and respiratory system and the outside environment. (Matthew N. Cramer et al., 2022). Wearing clothes reduces the rate of heat loss to the environment (Matthew N. Cramer et al., 2022). A heat load induces a physiological response, such as an increase in body temperature or heart rate, referred to as "heat strain" rather than "heat stress" (Matthew N. Cramer et al., 2022). Physical activity in a hot environment causes physiological and perceptual reactions that are connected with exercising at a certain rate to intensify, which impairs endurance capacity (Periard et., 2021). This impairment is exacerbated over time by gradual dehydration caused by increased sweat loss in hot weather, which reduces evaporative heat loss and places additional load on the heart (Periard et., 2021). In addition, prolonged exposure to heat stress, such as in simulated or natural climate changes, may increase the risk of cardiovascular disease, can result in changes that improve fluid balance and increase cardiovascular stability (Periard et., 2021). While the terms of heat acclimatization and heat acclimation are evoked in various contexts, they produce similar physiological adaptations (Periard et., 2021). A further approach developed by the military is a self-paced exercise-heat acclimatization strategy that is intended to protect large groups of recruits during basic training and prepare unacclimatized soldiers for deployment to hot climates in a short period of time (Periard et., 2021). It has been shown that self-paced heat acclimatization in an athletic environment can provide a sport-specific method for generating adaptation in a group of individuals who exercise simultaneously and self-regulate their effort according to their fitness levels, training demands, and ambient temperature (Periard et al., 2021).

2.1 Heat Balance

In terms of heat balance, the equilibrium between the rate at which the body generates heat within itself and the rate at which it exchanges heat with the surrounding environment has been referred to as the human heat balance (Matthew N. Cramer et al., 2022). In accordance with the first rule of thermodynamics, the conceptual equation for heat balance summarizes the flow of energy between a body and its environment:

$$S = M - Wk - K - R - C - E - C_{res} - E_{res} \, [W]$$

It is determined that the rate of dry heat transfer from the surface of the skin (M), the rate of radiation (R), the rate of convection (C), and the rate of evaporation (E) from the surface, as well as the rate of heat storage are determined by the rate of heat transfer by convection (Cres) and by evaporation (Eres) from the respiratory tract (S) (Matthew N. Cramer et al., 2022). It should be noted that metabolic energy may only be used to generate heat and work, which implies that M - Wk represents the rate of metabolic heat generation (Matthew N. Cramer et al., 2022). Human heat balance is primarily influenced by four external factors: ambient temperature, humidity, air velocity, and sun radiation (Julien D. Périard et al., 2021). Personal criteria such as body surface area, body mass, sex, age, and aerobic fitness as well as task dependant indicators such as rate metabolic heat production also impact heat exchange (Julien D. Périard et al., 2021). In the case of equal rates of metabolic heat generation and total heat loss, there is no net heat storage and no change in deep body temperature (Matthew N. Cramer et al., 2022). If the ambient temperature is excessively hot and humid, the metabolic energy generated exceeds the amount of heat lost (such as during non-steady-state exercise), which results in an increase in body temperature at the deep level (Matthew N. Cramer et al., 2022). Ultimately, total heat storage is the sum of metabolic heat production and heat loss over time, which is reflected in body heat content (Matthew N. Cramer et al., 2022).

2.2 Heat Production

To prevent an increase in core temperature, metabolic heat generation must be released into the environment (Bouscaren et., 2019). The equilibrium between heat production (such as exercise intensity) and dissipation (such as external heat, humidity and skin temperatures) is influenced by several factors (Bouscaren et., 2019).

Aerobic training, which improves aerobic fitness and reduces heat-related deficits, is a technique for reducing thermal stress, which results in more evaporative heat loss and improved core temperature management under high rates of metabolic heat production (MARTINS et., 2022). These changes work together to improve workout performance in the heat (MARTINS et., 2022). Because of the breakdown of stored macromolecules, metabolic rate represents the rate at which free energy is released (Matthew N. Cramer et al., 2022). An adult male's resting metabolic rate is defined as 1 MET, which is equivalent to 3.5 mL of oxygen per kilogram of total body mass per minute (Matthew N. Cramer et al., 2022). It can also be defined as the energy expenditure of 58.2 W/m2 (Matthew N. Cramer et al., 2022). As the intensity of exercise increases, so does the metabolic rate (Matthew N. Cramer et al., 2022). As work rate or running pace increases, the rate of metabolic heat production increases (Matthew N. Cramer et al., 2022). An increase in mechanical efficiency or movement economy reduces the need for heat storage, which in turn results in less metabolic heat being produced at a given speed or work rate (Matthew N. Cramer et al., 2022).

2.3 Heat Loss from the Skin

According to the second law of thermodynamics, the gradient for dry heat movement is the temperature differential between the skin and the surrounding environment (Matthew N. Cramer et al., 2022). As long as the skin temperature is higher than the surrounding temperatures, there is a positive thermal gradient and heat is transferred from the body to the environment (Matthew N. Cramer et al., 2022). The thermal gradient is negative if the ambient temperature is higher than the skin temperature, and heat is transferred from the environment to the body (Matthew N. Cramer et al., 2022). It is typically accepted that conductive heat transfer is minimal during exercise with passive heating, since the skin is rarely in contact with surfaces at different temperatures during exercise (Matthew N. Cramer et al., 2022). In thermal radiation, heat is transferred between objects with different surface temperatures using electromagnetic waves (Matthew N. Cramer et al., 2022). The sun is the primary source of radiant heat (Matthew N. Cramer et al., 2022). This thermal gradient determines the amount of radiant heat exchange by calculating the area-weighted average surface temperature of all radiating objects surrounding the body, as opposed to the mean skin temperature (Matthew N. Cramer et al., 2022).

3) Environmental Factors in Prolonged Exercise

Exercise intensity is the primary contributor to heat production, therefore longer sessions that are conducted at a lower intensity may be less likely to cause hyperthermia in a particular setting (Bouscaren et., 2019). ''For example, 68% of finishers in a half marathon in a tropical environment involving 31 heat-acclimated male soldiers had temperatures in the gastrointestinal tract greater than 40°C, whereas a 142 km trail run over six days in a tropical environment only had a maximum gastrointestinal temperature of 38.3-38.7°C'' (Bouscaren et., 2019).

The pressure exerted on the cardiovascular system is increased by environmental stress, particularly heat stress (Denby et., 2020). Exercise endurance affects the cardiovascular system as well, and when combined with heat stress, this can create a physiological challenge where demands for blood flow start to exceed the heart's maximum output, finally resulting in tiredness, fatigue, and a loss in performance (Denby et., 2020).

ENVIRONMENTAL FACTORS:

AMBIENT TEMPERATURE

The average temperature in the US, Africa, and the Middle East can soar to 54°C while it can plunge to -89°C in the Antarctic, making it difficult for humans to maintain a constant body core temperature (Periard et., 2021). Exercise resulted in sensible heat gain when ambient temperatures were higher than skin temperature, but exercise resulted in heat loss when ambient temperatures were lower (Periard et., 2021). The combination of high ambient temperatures and low humidity levels facilitates the evaporative loss of heat because sweat and mucosal moisture evaporate more readily under these conditions (Periard et., 2021).

HUMIDITY

Climate is directly affected by the humidity of the air (Periard et., 2021). Tropical forest regions are typically associated with hot, wet climates, while desert regions are generally associated with hot, dry climates (Periard et., 2021). As a result of the small difference between the surface of the skin and the atmosphere, high absolute humidity impairs the ability of the skin to drain perspiration (Periard et., 2021).

AIR VELOCITY

Based on the thermal gradient between the air and the skin, air displacement over the body results in convective heat exchange (Periard et., 2021). In addition to reducing evaporative heat loss, the removal of the saturated water vapor layer that can accumulate on the skin because of air displacement also contributes to this reduction.

SOLAR RADIATION

The location of the human body on the planet, the time of day, the season, and the amount of exposed skin area all influence the amount of solar radiation that enters the body (Periard et., 2021).

A multi-exposure perspective is included in the exposome idea (Münzel et al., 2021). The exposure of an individual is characterized by lifestyle and environmental factors, such as socioeconomic status and climate, as well as external environmental risk factors (such as traffic noise and air pollution) (Münzel et al., 2021). This assessment necessitates a multidisciplinary approach that employs smart sensor devices, multi-OMICs methodologies, and large data management techniques based on bioinformatics and systems biology (Münzel et al., 2021). Designing focused on policies and initiatives to lessen the enormous burden of diseases that can be attributed to environmental risk factors requires an understanding of the links between environmental risk factors and health (Hadley et., 2022). The majority of environmental factor studies to date have focused on individual risk factors in high-income environments (Hadley et., 2022).

4) CORE AND SKIN TEMPERATURE IN EXERCISE

Normally, the body's core temperature is maintained at 36.6°C, but it can differ significantly when exposed to harsh conditions (Julien D. Périard et al., 2021). The lowest body core temperature that a human endures is 13.7°C (Julien D. Périard et al., 2021). Conversely, well-trained athletes are able to exercise in the heat and reach body temperatures of 41.5°C without experiencing any adverse effects short-term or long-term (Julien D. Périard et al., 2021). The primary controlled variable in thermoregulation in humans is body core temperature (Julien D. Périard et al., 2021). Because of the local heat balance, the temperature of the body core is determined by the location (Julien D. Périard et al., 2021). At rest, the rectum usually registers the highest body core temperatures (Julien D. Périard et al., 2021). Additionally, factors such as ambient temperature, dew point, time of day, and month of the year affect resting body core temperature (Julien D. Périard et al., 2021).The body attempts to maintain a normal temperature as the internal temperature rises by sweating, boosting blood flow and reducing the amount of physical activity possible to protect the central nervous system (Morito et., 2022). For athletes, cooling techniques are crucial since elevated core temperatures can hinder workout performance (Morito et., 2022). Unlike core temperature, skin temperature is unregulated and varies with the weather conditions (Julien D. Périard et al., 2021). The skin serves as the body's contact with the environment (Julien D. Périard et al., 2021). However, mean skin temperature can be divided into three categories: mild (30°C), warm (30-34.9°C), and hot (>35°C) (Julien D. Périard et al. 2021). With reference to temperature, the human body is typically split into the core and shell (Julien D. Périard et al., 2021). A third compartment of the muscle is injected regularly to detect variations in body heat content (Julien D. Périard et al., 2021). It is possible to estimate the mean body temperature more precisely with a three-compartment model, although it is intrusive to measure the temperature of the muscles during exercise (Julien D. Périard et al., 2021). While an increase in core temperature may impair performance during prolonged exercise in hot and humid conditions by stressing the circulatory system, an increase in muscle temperature actually increases performance during explosive efforts (Bouscaren et., 2019). In a nutshell, as the temperature difference between the core and the skin narrows, blood flow is diverted toward the skin to dissipate heat (Bouscaren et., 2019). An inherent rise in heart rate exacerbates the ensuing reduction in ventricular filling pressure, which reduces stroke volume (Bouscaren et., 2019). Maintaining a high sweat rate for heat dissipation may also result in dehydration if fluids are not supplied (Bouscaren et., 2019). It is a system in which a feedback control signal is generated and used to trigger effectors in order to limit the displacement of the variable to a specified value (Matthew N. Cramer et al., 2022). Sensors detect the displacement of the regulated variable and send it to the controller (Matthew N. Cramer et al., 2022). A rise in body temperature is transmitted to the brain through the spinal cord, which generates an efferent instruction to activate the neurotransmitters that cause cutaneous vasodilation and sweating (Matthew N. Cramer et al., 2022).Heat loss thermal effectors do not immediately activate instead, they need a specific load error to start working (Matthew N. Cramer et al., 2022). Upon activation of the heat loss thermo effectors, the output rises proportionally to the increase in deep body temperature, until steady-state levels or maximum levels are reached (Matthew N. Cramer et al., 2022). Activating thermo effectors of heat loss alters the body's exchange of heat with the environment thereby reducing the rise in deep body temperature that feeds back to continuously fine-tune the temperature output of the thermo effectors (Matthew N. Cramer et al., 2022). In addition to deep body temperature, skin temperature also affects thermo afferent flow during heat stress (Matthew N. Cramer et al., 2022). Although variations in deep body temperature influence response time and the magnitude of thermo effectors output, skin temperature remains an auxiliary variable (Matthew N. Cramer et al., 2022). A rise in deep body temperature will cause thermo effectors to operate more rapidly and produce more heat if the skin temperature is warm during heat stress, whereas a rise in skin temperature will delay thermo effectors activation and output if the skin temperature is cool during heat stress (Matthew N. Cramer et al., 2022).

It should be highlighted that the regulating role of skin temperature in humans cannot be attributed simply to a neurological effect (Matthew N. Cramer et al., 2022).

5) HEALTH AND PERFORMANCE IN EXTREME ENVIRONMENTS

When compared to a temperate environment, hot weather can have both beneficial and negative effects on athletic performance and mid-to-long distances (Bouscaren et., 2019).Tropical environments present a tough physiological barrier for physical performance that calls for special preparation (Hermand et., 2019).

For optimal athletic performance and safety during training and competition in the heat, adequate hydration is essential before, during, and after the event (Bouscaren et., 2019). To avoid impairments of thermoregulatory function, an increase in cardiovascular strain, and an impairment of aerobic exercise performance in many circumstances, athletes should avoid body water deficits during an activity that exceeds 2% of their body mass (Bouscaren et., 2019). Sustained high-intensity exercise is negatively impacted by the harshness of the thermal environment, which is determined by the interaction of ambient temperature, absolute humidity, sun radiation, and wind speed (Periard et., 2021). When compared to exercising in temperate conditions, the impairment is characterized by an excessive development of whole-body hyperthermia, which causes a quicker onset of tiredness during exercises at a constant work rate or a gradual decrease in work rate during exercises at a self-paced pace (Periard et., 2021). According to the severity of the environmental conditions and initial thermal strain (core and skin temperatures), maximum aerobic power (VO2max), a critical factor in determining endurance performance, is also affected during heat stress (Periard et., 2021). Many physiological systems interact to cause performance impairments in the development of hyperthermia-induced weariness (Periard et., 2021). These physiological reactions impact perceptions, which can influence performance by diminishing motivation and decreasing the desire to continue working out in the heat (Periard et., 2021). Under heat stress, endurance exercise is compromised, and a lack of hydration exacerbates the harmful consequences of thermal strain (Periard et., 2021). The degree of physiological stress brought on by hyperthermia and dehydration depends on the amount of thermal stress and water lost from the body, the type and intensity of exercise being done, the ambient circumstances, and more (Periard et., 2021). As a result of hyperthermia and rising dehydration during prolonged exercise, a decrease in the systemic, cutaneous, active muscle and cerebral blood flow can significantly affect thermoregulatory capabilities (Periard et., 2021). When exercising at intensities above 60% VO2max, there is a loss of systemic and regional perfusion associated with a decrease in cardiac output, an increase in peripheral resistance, and a decrease in mean arterial pressure (Periard et., 2021).

Figure

Impacts of extreme environmental conditions on Humans Performance and Health and ways to prevent it.

Extreme environment	Impacts on human's performance and health risks	Ways to prevent it
Heat	high body temperature Headache Muscle pain dizziness	stay hydrated wear right clothing stay in cool areas pace yourself acclimatization
Altitude	Altitude illness Hypoxia	know the early symptoms of altitude illness, never ascend to sleep at high elevations
Outer space	Radiation(cardiovascular disease) Isolation(behavioral impacts) Altered gravity fields(balance disorders)	physical training appropriate clothing technology
Deep ocean	Pollution Drowning Injuries	Training, Right equipment for dive Monitor devices
Cold	hypothermia, frostbite	warm clothes, acclimatization

When prolonged exercise is conducted in a well-hydrated condition with adequate systemic and skeletal muscle blood flow, both in cool and hot settings, the delivery of substrates and elimination of metabolites are well matched (Periard et., 2021). Long-term submaximal heat activity was tested in both hydrated and dehydrated states, with and without exhaustion (Periard et., 2021). A 120-minute period of no exhausting exercise was followed by fluid ingestion for the preservation of intracranial and extra cranial blood flow, whereas progressive dehydration (3% body mass loss) and greater hyperthermia (0.5°C) resulted in accelerated decreases in blood flow in the internal carotid artery and MCAV, as well as an increase in blood flow in the extra cranial region (Periard et., 2021). Malnutrition from food insecurity, infectious diseases, respiratory, cardiovascular, neurological, and mental health concerns, as well as mortality, are only a few of the numerous negative repercussions of these weather extremes on human health (Koch, M. et., 2022). Wearables have been successfully used in an extensive study to assess the health effects of weather extremes connected to climate change (Koch, M. et., 2022).

CHAPTER 3: MATERIALS AND METHODS

PARTICIPANTS

This study included 16 endurance acclimatized athletes (age: 37-71 yr, height: 172.5±12.5 cm, weight: 70±20 kg). All the participants had no history of chronic health problems, were not taking any medications, and had no muscle injury. All participants were informed verbally about the procedures of the study, including possible risks and discomforts. Following their agreement to participate, they signed a written informed consent before the race and completed a questionnaire on the conditions that they faced after the race. The research took place in two half-marathons: Ioannina (8 May 2022) and Falani (22 May 2022). The participants were 11 in Ioannina and 5 in Falani.

EXPERIMENTAL PROTOCOL

First, I had a few minutes of conversation with each participant before the race to explain the kind of research this is and how this will help us to understand better the performance of humans in extreme environmental conditions such as heat.

The participants raced in 2 half-marathons (11 in Ioannina and 5 in Falani) under heat-stress and with 4 skin sensors, a pill for core temperature, a heart rate monitor and a urine sample before and after the race. After they completed the race, all of them, we took their skin sensors, heart rate monitors, urine samples to analyze the effect of the pill with the help of a small device that monitored the results of each participant's core temperature. After that, they answered a questionnaire about the conditions that they faced during the half-marathon.

Then, we took the physical elements of each volunteer and put them in software called PHS (Predicted Heat Strain). There, we can compare the simulated results (core temperature and skin temperature) with the exact real conditions they faced in the race and then compare T_c (PHS) with T_c (real conditions) and T_{sk} (PHS) with T_{sk} (real conditions) to see how reliable the software is. Also, we measured bias-corrected effect sizes to see if there is any significant effect size difference between T_c (PHS) and T_c (real conditions) and T_{sk} (PHS) and T_{sk} (real conditions).

MEAUSUREMENTS

• We took a urine sample to measure the specific gravity, so that in this way we can make a diagnosis for various diseases in their kidneys.

Picture: Urine cup

• We put a polar (V800, Polar Electro, Kempele, Finland) on a volunteer to measure his heart rate during the race. Then, we transferred them to the computer for data analysis.

Picture: Polar heart rate monitor

• Also, 4 sensors (SmartReader Plus 3, Surrey, British Columbia V3S 5X7 Canada) were used to measure skin temperature. We placed these sensors on the same side of the body (left or right) in 4 places (pectoralis major, biceps brachii, quadriceps femoris and gastrocnemius). The iBUTTON sensors is a compact (16 x 6 mm2) instrument that measures and stores temperature data in a secure memory section. The data, such as time and temperature, were then transmitted to a computer for processing.

Picture: i-buttons

• Telemetry capsules (CoreTemp, HQInc., Sarasota, Florida, USA) that he/she swallows to measure his/her core temperature during the race.

Picture: capsules CoreTemp

- Meteorological indicator (heat stress tracker) at a high point to record all the elements of the ambient temperature. We placed the Kestrel high (tree) to record the ambient temperature per second. We connected to the computer using the Kestrel program to study and appraise the arena temperature.

Picture: Kestrel 5400 FW

PHS SOFTWARE

Main screen of Predicted Heat Strain

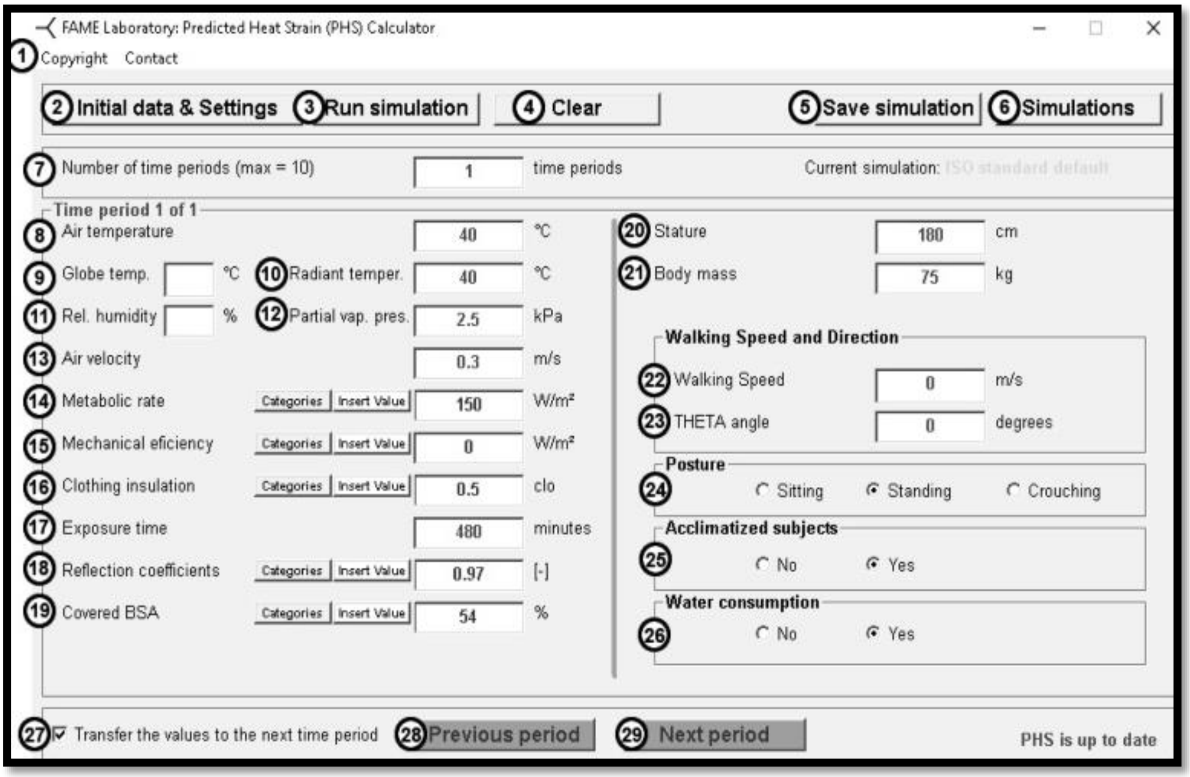


Figure: Fame lab Predicted Heat Strain (IOANNOU et., 2019)

PHS can be freely downloaded on Fame Lab page and everyone can use it for their scientific research. It is a method to simulate the heat strain of an individual person who is exposed to various environmental and physiological stresses.

We used the software PHS calculator to predict the T_c and T_{sk} of volunteers and how close are the results compared to the real conditions of T_{sk} and T_c. This is how we will test the credibility of PHS and how accurate it is.

Figure: Research questionnaire that volunteers answered after the race. It was important because we wanted, beyond the statistic results, to see the answers of the volunteers and how they felt during the race so to have a more subjective opinion):

1. Name:
2. Weight:
3. Height:
4. How satisfied are you with your performance? 1 (not at all) to 10 (very much):
5. How much fatigue did you feel during the race: With +
Very light
Fairly light
Kind of heavy
Very heavy
Exhausting
6. How hot or cold did you feel the environment during the race:
Very cold
Slightly Cold
Normal
Slightly Warm
Very hot
7. How did you feel your body temperature during the race:
Comfortable
Slightly uncomfortable
Uncomfortable
Very uncomfortable
Too uncomfortable

8. How many years have you been playing sports:
9. Workouts per week:
10. How many competitions have you participated in:
11. Have you ever had any following diagnoses:
Cardiovascular diseases
Respiratory diseases
Diabetes
Hypertension
Cholesterol
Nephropathy
Cancer
Hepatitis
Blood disease
None of the above
Other:
12. During the last year, have you experienced levels of stress, tension and pressure that could affect your health? YES NO
13. Do you need to take any medication to be able to compete?
YES NO
14. Have you experienced negative thoughts during the race that lead you to a lack of concentration and low performance? YES NO
15. Have you experienced positive thoughts during the race that lead you to better concentration and high performance in the race? YES NO
16. Which factors in your opinion played a major role in your performance?
List some for me in 2-3 lines below.
17. Did the ambient temperature during the race have any changes that affected you, in your opinion, physically and psychologically? In other words, you could feel the temperature sometimes rising and sometimes falling, even for a short period.
YES NO
18. Do you eat foods high in fat and cholesterol (eg fatty meats, cheeses, fried foods, butter, whole milk, eggs) on a daily basis?
YES NO
19. Do you tend to avoid foods high in fiber (eg whole grain breads and cereals, fresh fruits and vegetables)?
YES NO
20. You have experienced fainting or dizziness during prolonged exercise in a hot environment
YES NO

THE ENVIRONMENTAL CONDITIONS OF HALF-MARATHONS

Falani half marathon (example of one volunteer PHS)

Air temperature:	26.5 °C
Globe temperature:	29.6 °C
Mean Radiant temperature:	32.17 °C
Relative humidity:	46%
Vapor pressure:	1.59 kPa
Air velocity:	0.18 m/s
Metabolic rate:	569.87 W/m²
Mechanical efficiency:	113.6321 W/m²
Clothing insulation:	0.22 clo
Exposed time:	135 minutes
Reflection coefficients:	0.97(-)
Covered BSA:	61%

It is important to mention that the metabolic rate and the mechanical efficiency are different to each participant in Falani because its participant has different time finished and body stature.

Ioannina half marathon (example of one volunteer PHS)

Air temperature:	20.5 °C
Globe temperature:	27.56 °C
Mean Radiant temperature:	43.48 °C
Relative humidity:	44.20 %
Vapor pressure:	1.07 kPa
Air velocity:	1.03 m/s
Metabolic rate:	639.65 W/m²
Mechanical efficiency:	127.7381 W/m²
Clothing insulation:	0.22 clo
Exposed time:	113 minutes
Reflection coefficients:	0.97 (-)
Covered BSA:	61%

It is important to mention that the metabolic rate and the mechanical efficiency are different to each participant in Ioannina because its participant has different time finished and body stature.

STATISTICAL ANALYSIS

For the statistical analysis of the data, the SPSS statistical analysis package was used. A value of $p<0.05$ was defined as the coefficient of statistical significance. **Paired Samples t-test** was conducted to find whether there are differences in the dependent variable between T_c (PHS) and T_c (real conditions) and T_{sk} (PHS) with T_{sk} (real conditions). **Correlation Analysis** was conducted to examine the relationships between two or more continuous (quantitative) variables between T_c (PHS) and T_c (real conditions) and T_{sk} (PHS) with T_{sk} (real conditions). Also, we used **effect size calculation** or else Bias Corrected to analyze if there is any significant effect size between T_c (PHS) with T_c (real conditions) and T_{sk} (PHS) with T_{sk} (real conditions).

CHAPTER 4: RESULTS

For statistical analysis of the data, the SPSS package was used.

Correlation analysis was conducted to examine the relationships between T_c (PHS) with T_c (real conditions) and T_{sk} (PHS) with T_{sk} (real conditions). The results revealed a statistically significant relationship between T_c (PHS) with T_c (real conditions) because (Sig. (2-tailed) = .004, $p<.05$). The results revealed that there is a statistically significant relationship between T_{sk} (PHS) with T_{sk} (real conditions) because (Sig. (2-tailed) = .000, $p<.05$).

Correlations

		CORE_R	CORE_PHS
CORE_R	Pearson Correlation	1	-,187**
	Sig. (2-tailed)		,004
	N	232	232
CORE_PHS	Pearson Correlation	-,187**	1
	Sig. (2-tailed)	,004	
	N	232	504

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		SKIN_REAL	SKIN_PHS
SKIN_REAL	Pearson Correlation	1	-,228**
	Sig. (2-tailed)		,000
	N	1945	1945
SKIN_PHS	Pearson Correlation	-,228**	1
	Sig. (2-tailed)	,000	
	N	1945	1945

**. Correlation is significant at the 0.01 level (2-tailed).

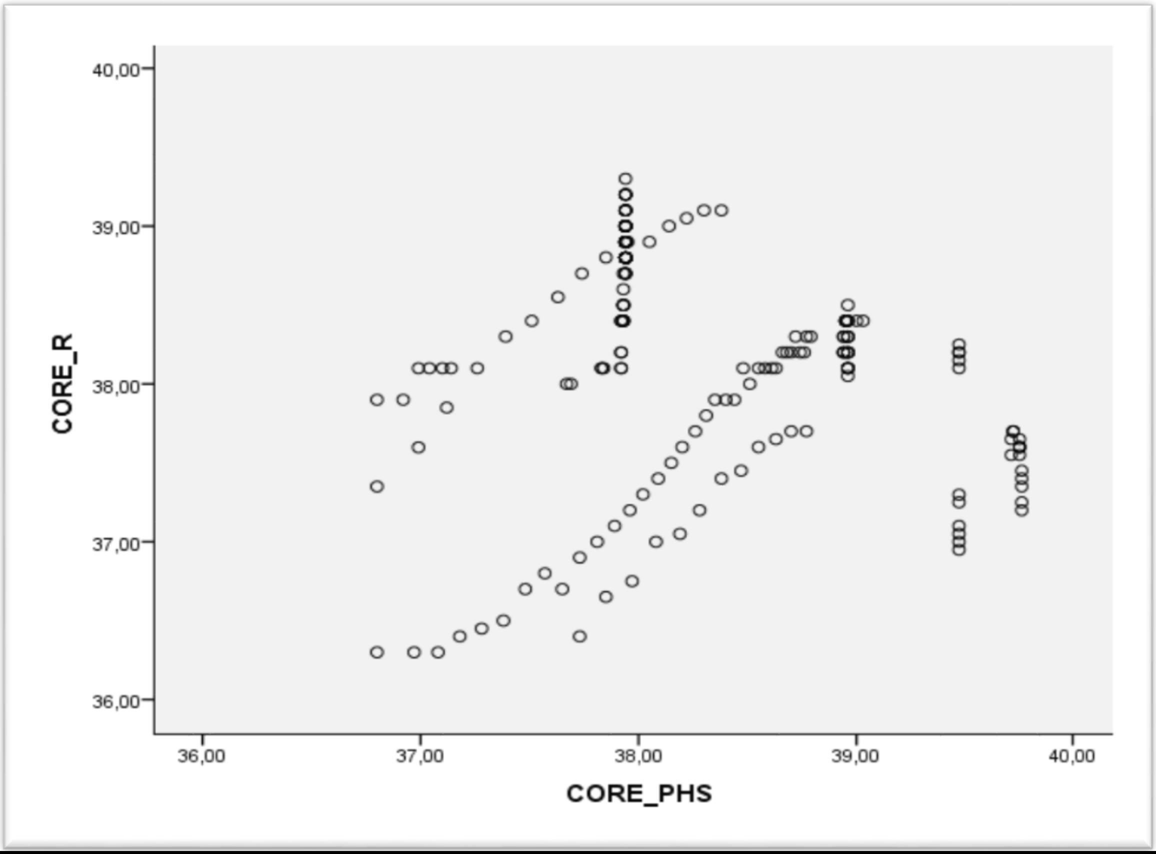
Paired samples t-test was conducted to find if there are differences in the dependent variable between T_c (PHS) and T_c (real conditions) and T_{sk} (PHS) with T_{sk} (real conditions). The results revealed that between T_c (PHS) and T_c (real conditions) that there are NO statistically significant differences (Sig. (2-tailed) = .665 p>.05). But the results between T_{sk} (PHS) with T_{sk} (real conditions) revealed that there is statistically significant differences (Sig. (2-tailed) = .000 p<.05).

Paired Samples Test Core Real and PHS (IOANNINA)

Mean	Std. Deviation	t	df	Sig. (2-tailed)
.03034	1,06622	,433	231	,665

GRAPH 1

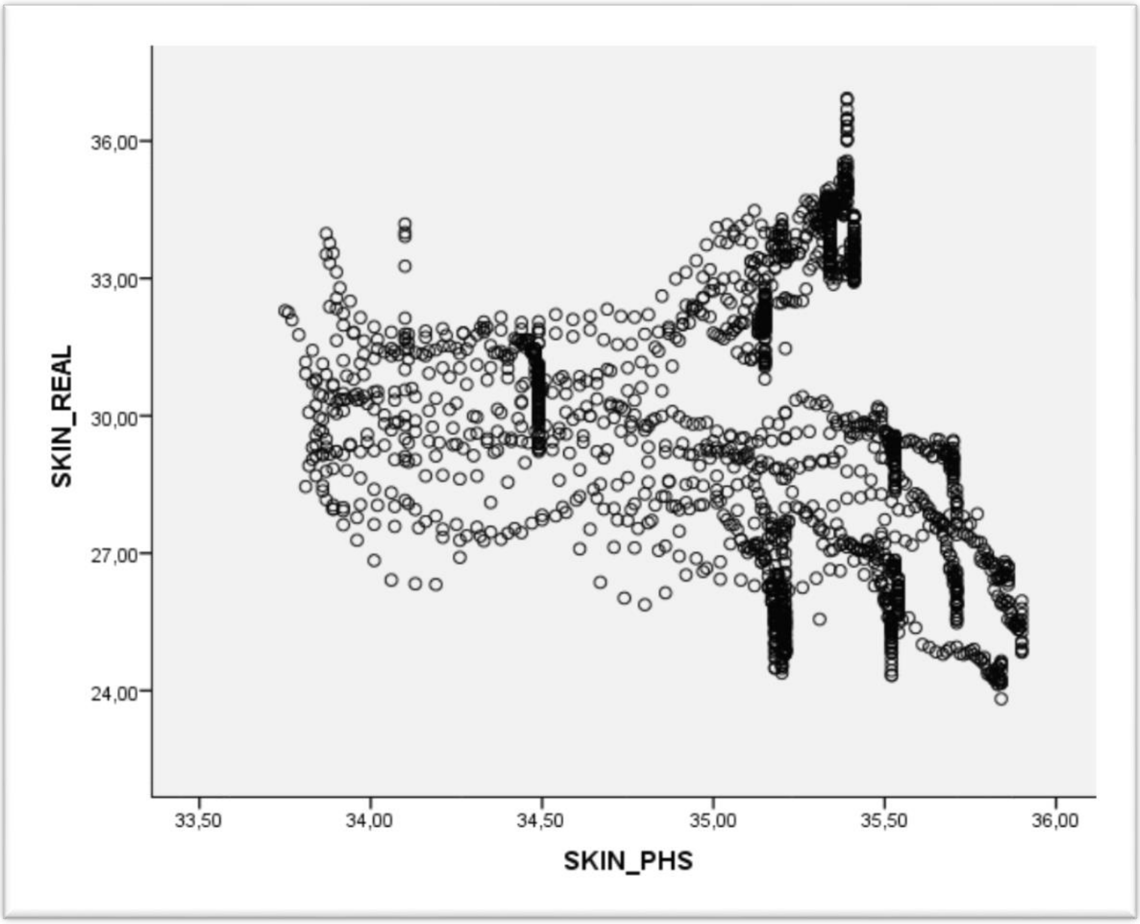
CORE Real conditions and PHS(Ioannina)



Paired Samples t-test Skin Real and PHS (IOANNINA AND FALANI)

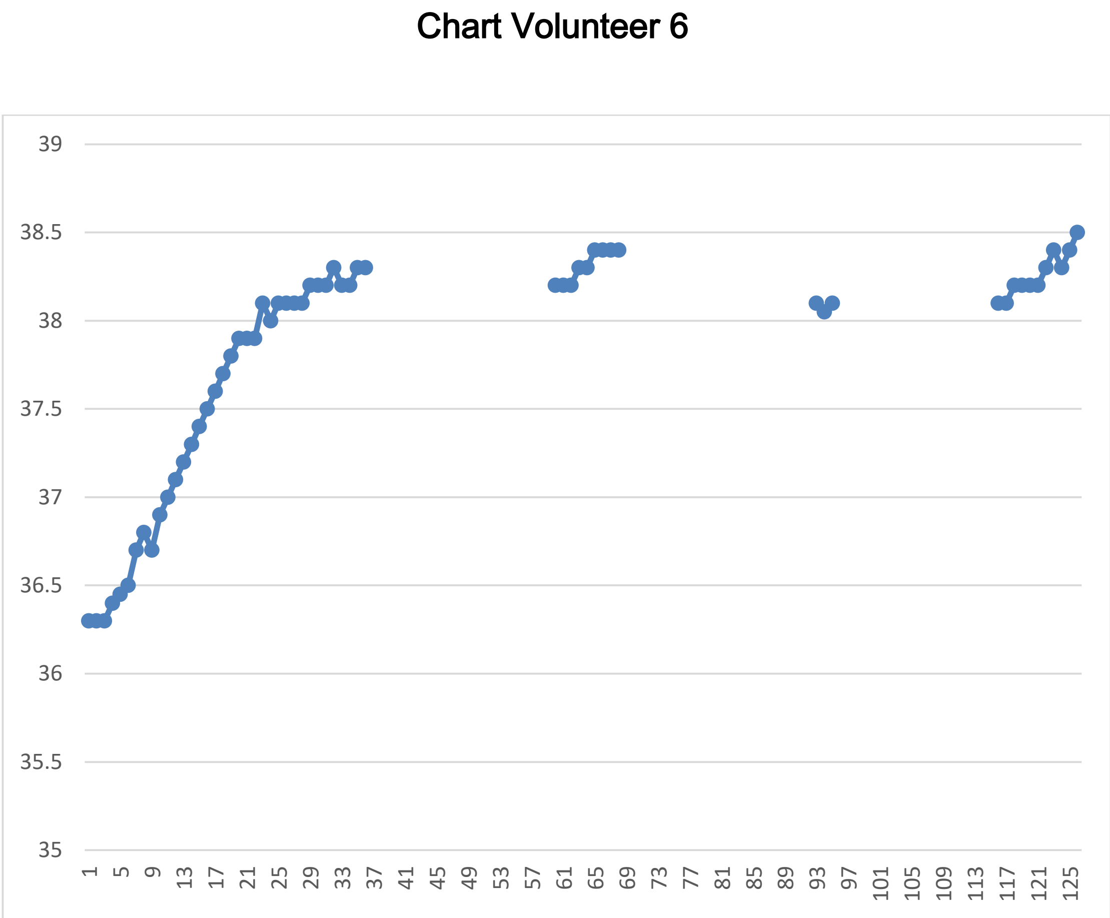
Mean	Std. Deviation	t	df	Sig. (2-tailed)
-5,49476	3,21358	-75,408	1944	,000

GRAPH 2
SKIN Real conditions and PHS(Ioannina and Falani)



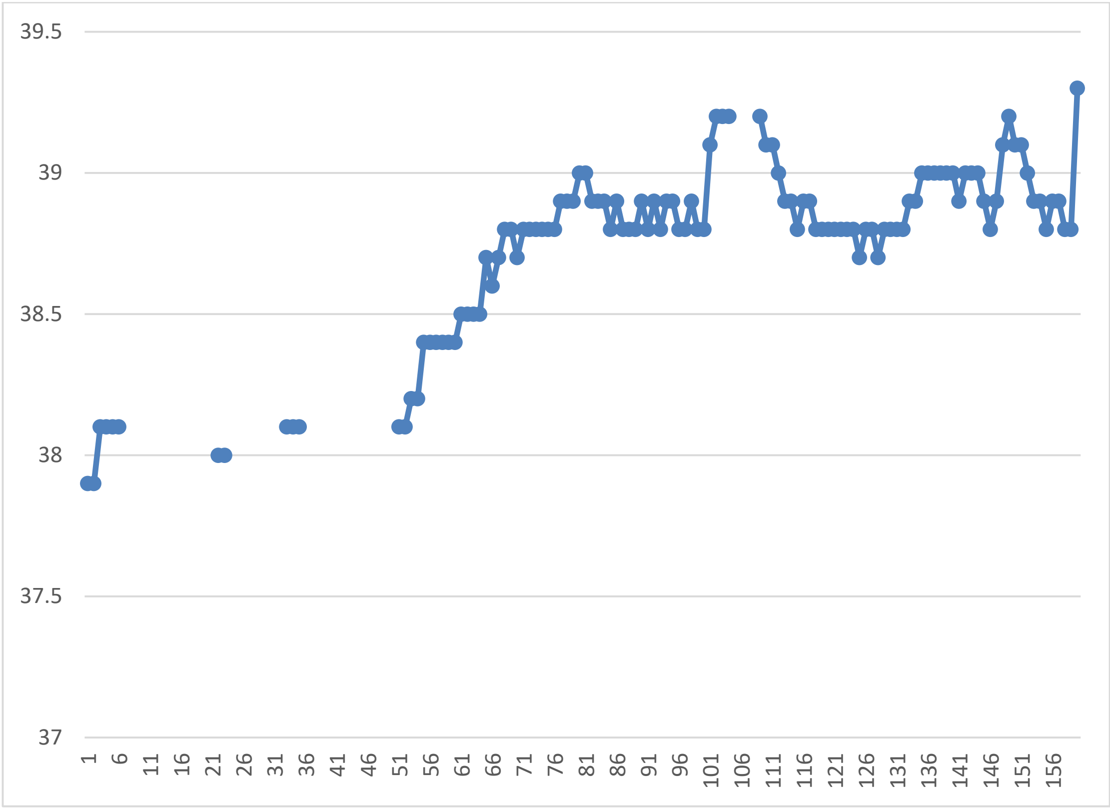
The results showed that volunteers managed to finish the half-marathons under heat stress. The core temperature of the volunteers in Ioannina (real conditions) is very close to the simulation PHS, but the skin temperature of Ioannina and Falani (real conditions) is not so close as we can see from the statistical analysis.

Graphs from one of the volunteer's core temperature (real conditions) in Ioannina:



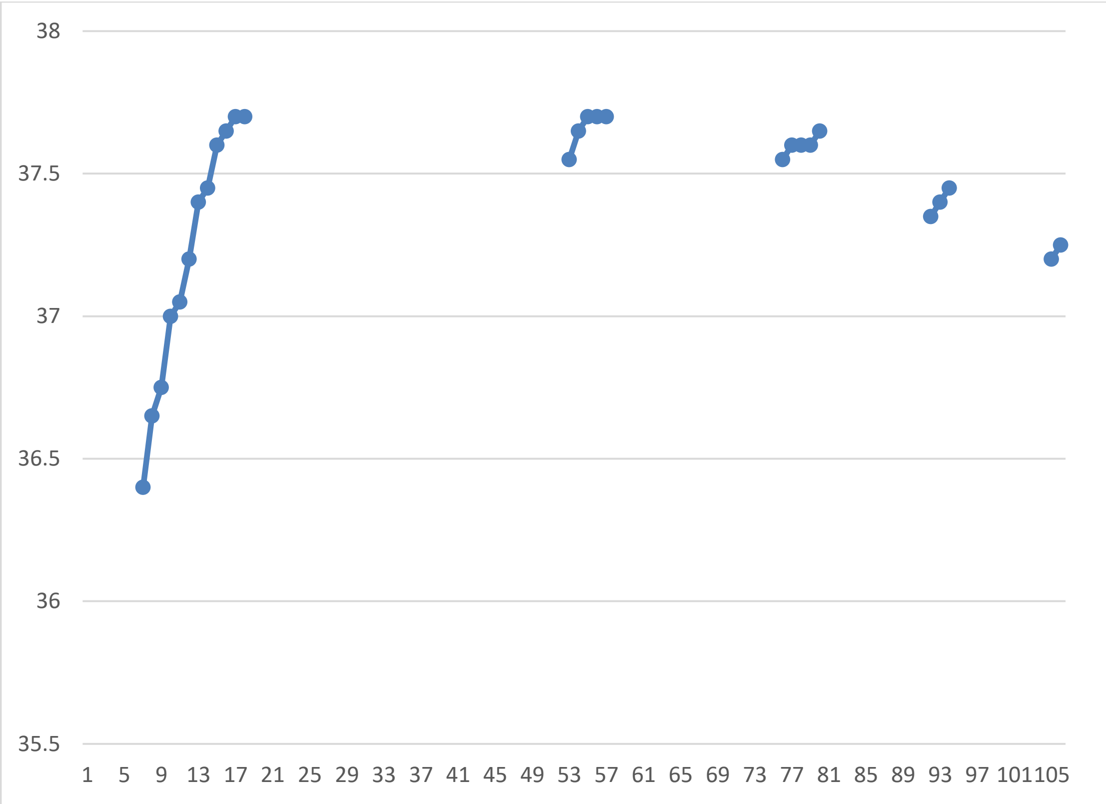
We see in the Chart of volunteer 6 that there is empty in some lines and that indicates that while they were drinking water during that time, this means that water can affect the measurements of the results of the pill for the core temperature.

Chart Volunteer 9



We see that there is empty in some lines and indicates that they were drinking water during that time and water often affects the measurements of the core temperature results of the pill. The average core temperature of the volunteers in Ioannina was 38-38.5°C and none of them reached 40°C.

Chart Volunteer 5



We see in the Chart of volunteer 5 that there is empty in some lines and that indicates that while they were drinking water during that time, this means that water can affect the measurements of the results of the pill for the core temperature.

Graphs from one of the volunteer's skin temperatures (real conditions) in Ioannina:

Chart Volunteer 1

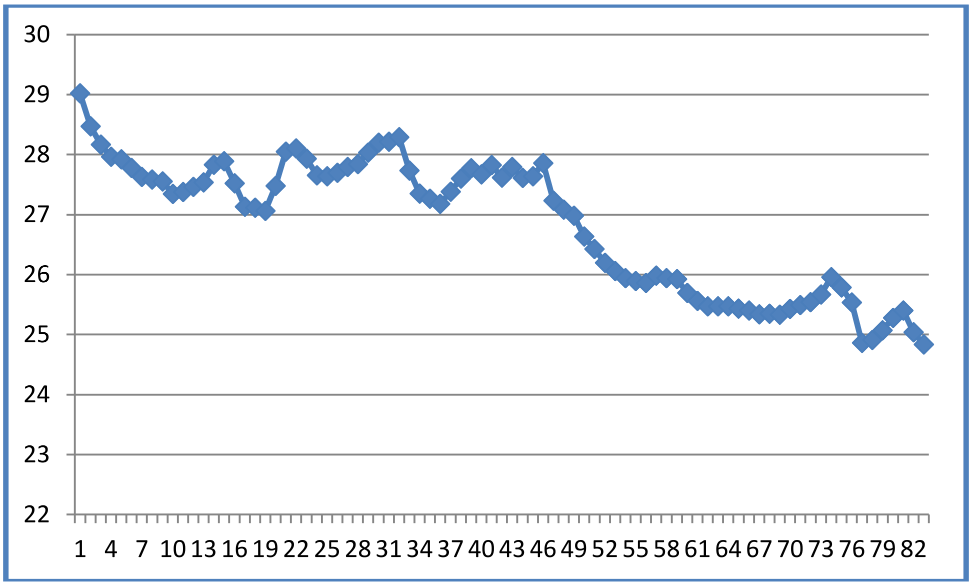


Chart Volunteer 3

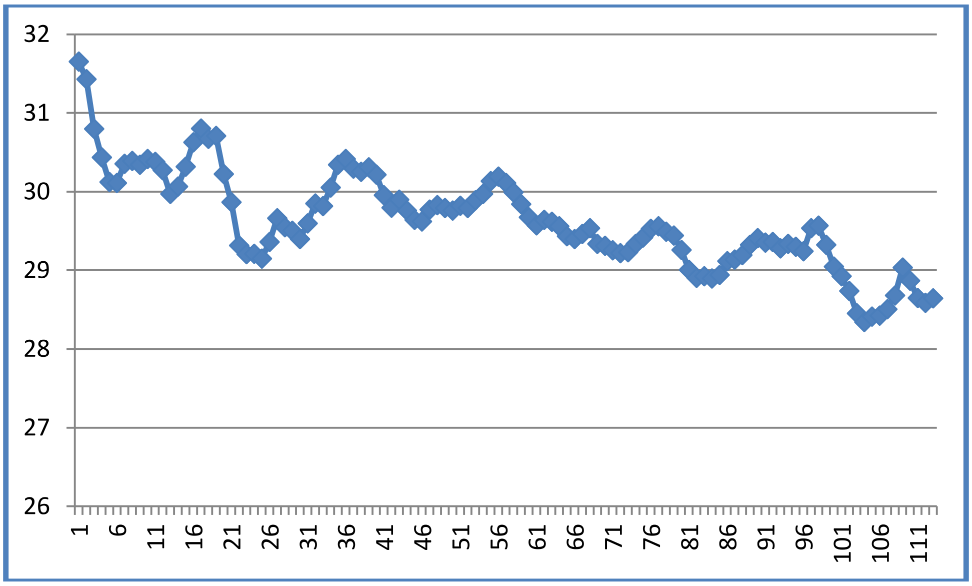
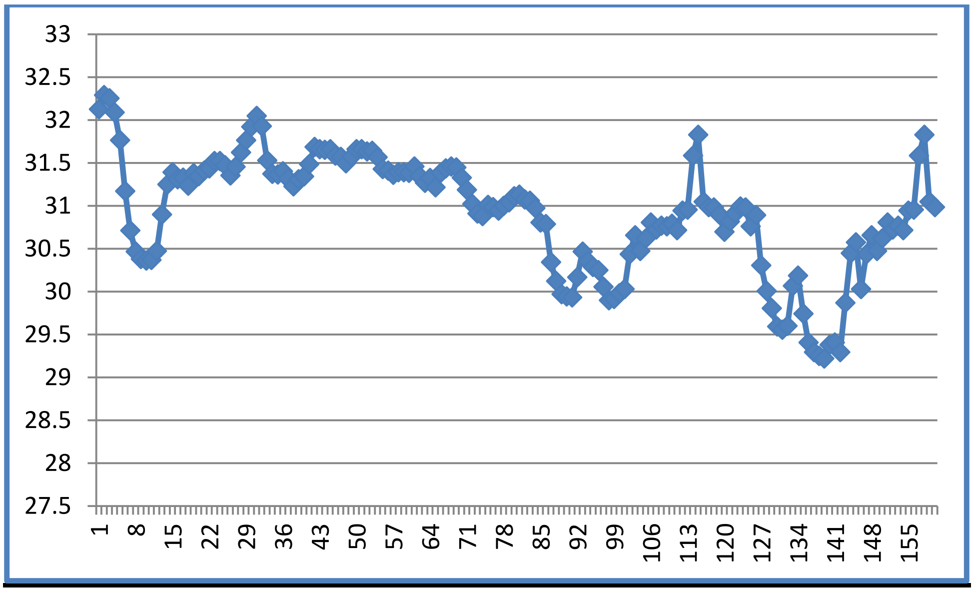


Chart Volunteer 9



Graphs from one of the volunteer's skin temperature (real conditions) in Falani:

Chart Volunteer 1

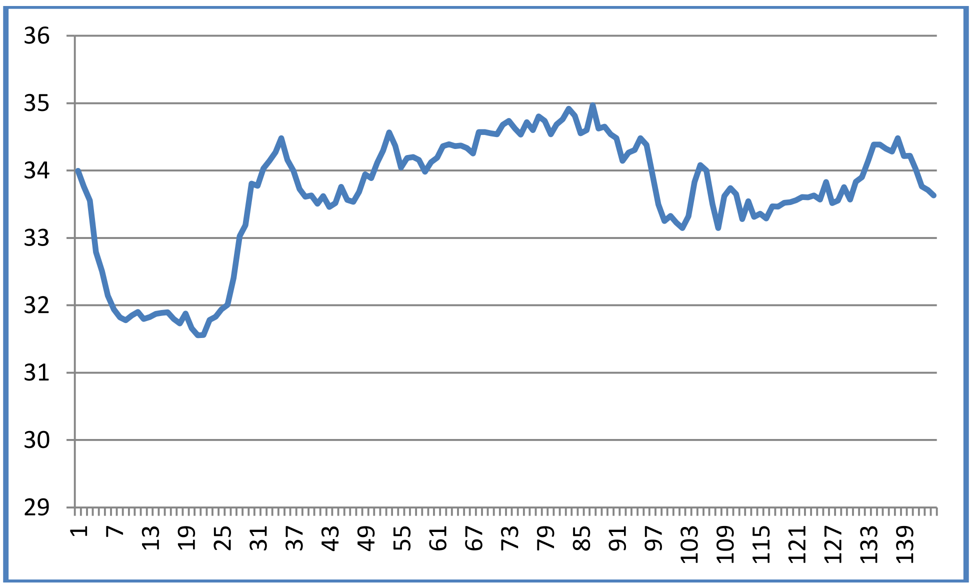
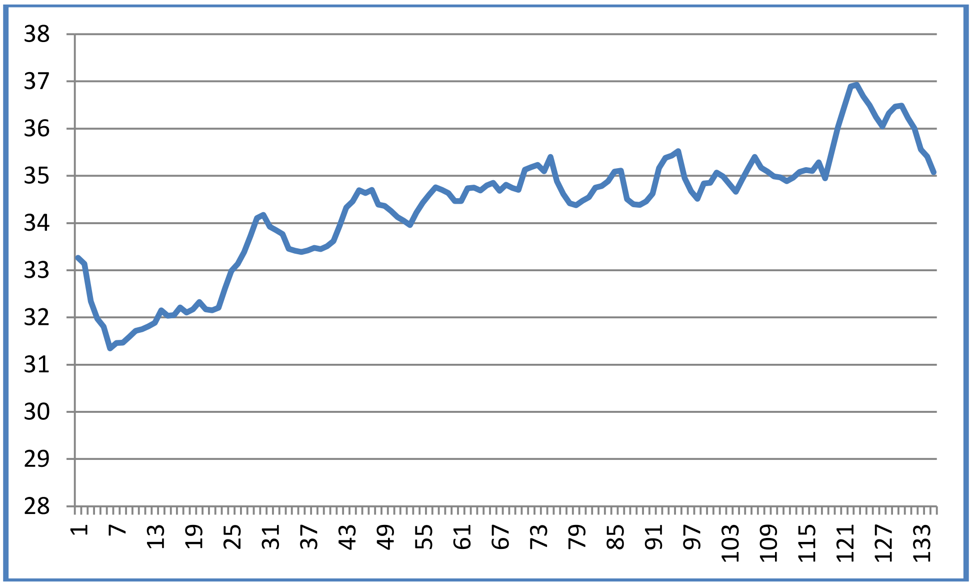
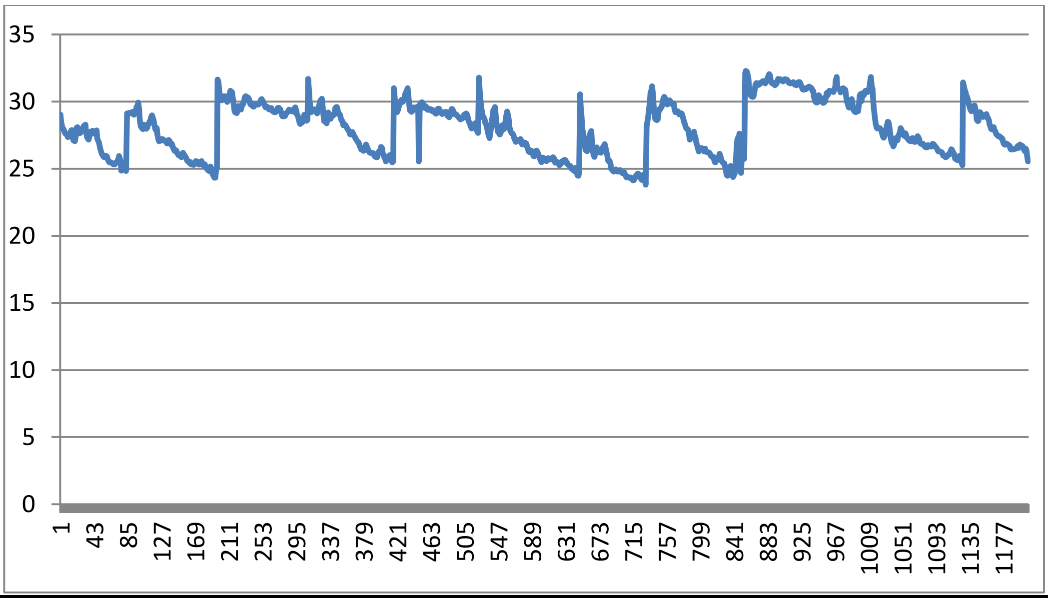


Chart Volunteer 3

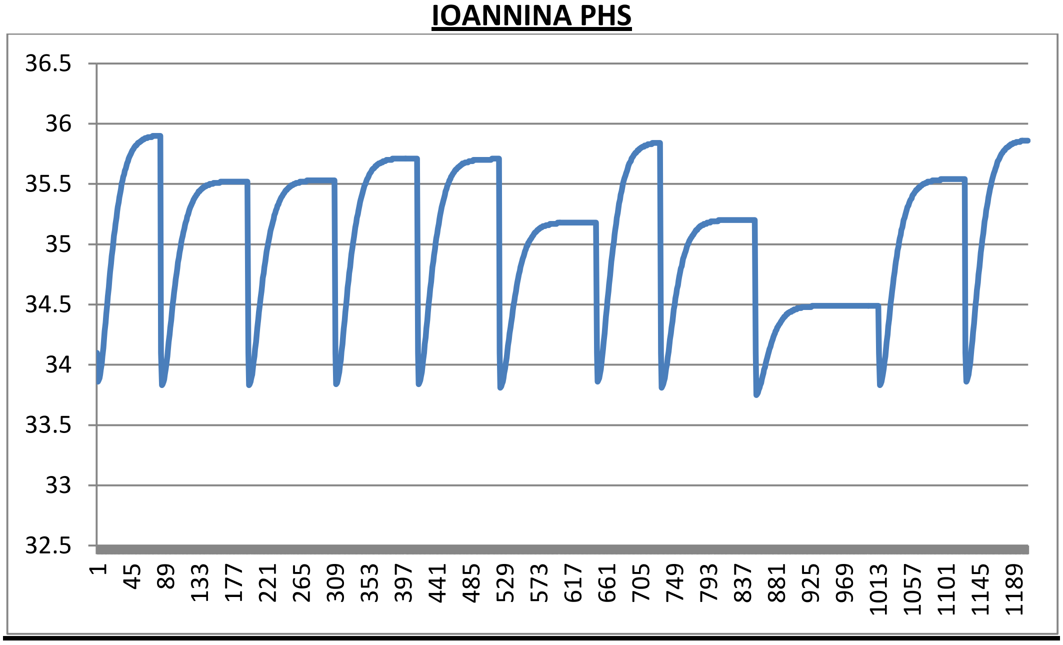


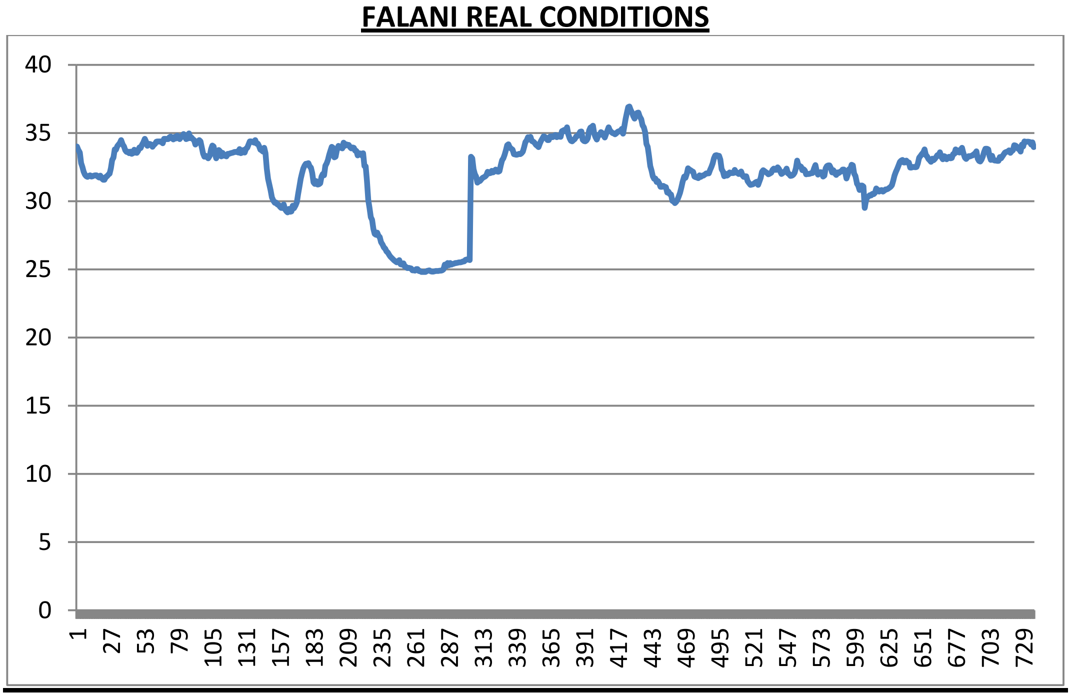
MEAN SKIN TEMPERATURE REAL CONDITIONS AND PHS

IOANNINA REAL CONDITIONS



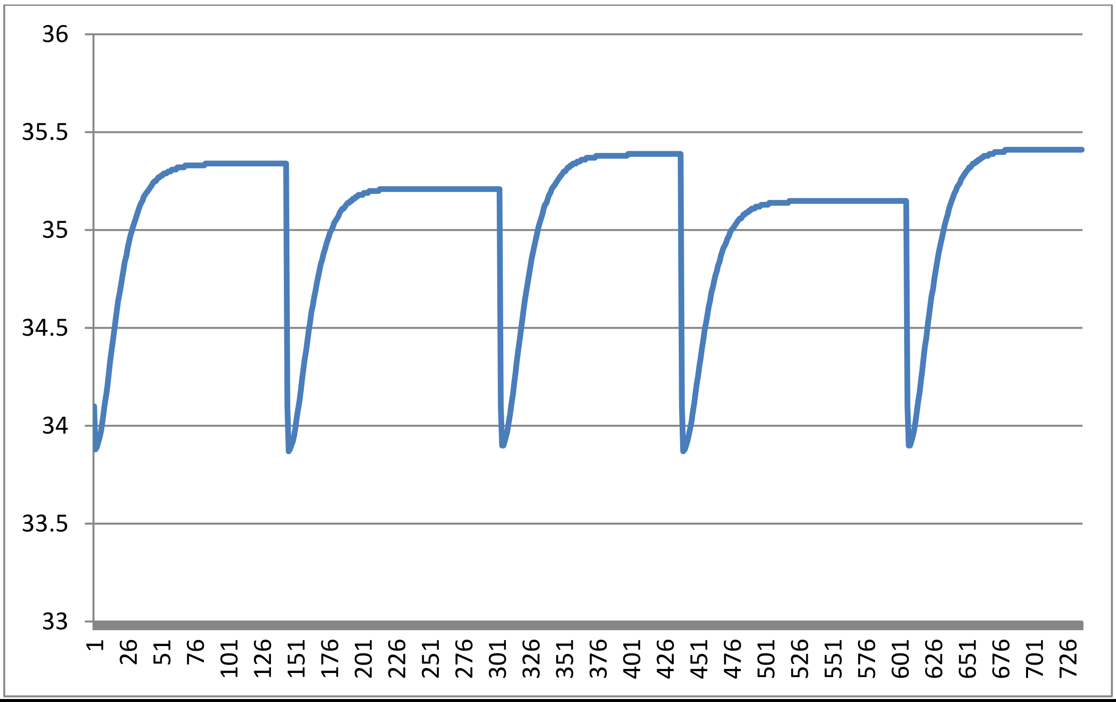
The results indicate from the graphs that the mean skin temperature of athletes in Ioannina was falling in real conditions from 30 to 25°C but in PHS the mean skin temperature was holding 34 to 35.5°C. This reveals that there is a large difference in skin temperature and that PHS is inaccurate when it comes to predicting the results of skin temperature.





There is a small difference with the mean skin temperature of athletes in Falani because in real conditions, the skin temperature was between: 30-34°C and in PHS: 34-35.5°C.

FALANI PHS



EFFECT SIZE CALCULATION (BIAS CORRECTED)

We used bias corrected to see if there is any significant effect size between T_c (PHS) with T_c (real conditions) and between T_{sk} (PHS) with T_{sk} (real conditions).The results revealed that there is no significant effect size on the core temperature between real time and software PHS (0.04) and on skin temperature between real time and software PHS (2.51), there is a large effect size between these two.

RESEARCH QUESTIONNAIRE

The answers from the volunteers in the research questionnaire showed that the environment was very hot and they were feeling extremely uncomfortable in their body temperature during the race. This kind of environment that they faced in their opinion exhausted them and influenced their performance. This also brought negative thoughts and a lot of stress under these conditions. The majority of the volunteers were affected by the prolonged exercise in heat and for that their finish time was not so good, even though they were experienced athletes, and from their answers we ended up that the temperature of the environment by going up affected their physical and mental states during the race.

CHAPTER 5: DISCUSSION

We recognize that warm environments must be dealt with using the knowledge and technology that has been provided to us. Only in this way can we improve our performance as humans under extreme environmental conditions. Heat production during exercise endurance in a hot environment can also cause a rise in body core temperature, and any tool to prevent or deal with extreme conditions is crucial for human health. The PHS software has several features to improve its practicality, including a method to simulate the heat strain of an individual who is exposed to environmental stress. In the simulations, there were no statistically significant differences in T_c between the predicted and measured data. On the other hand, there were significant differences between the predicted and measured T_{sk} during the half marathon races. The PHS software demonstrated strong criteria and construct validity, especially in the prediction of core temperature. However, it is crucial to note that performing simulations with the PHS without the required fundamental knowledge of thermal and human physiology may result in improper use of the program and the potential development of suggestions that could jeopardize the health of those exposed to heat. We hope that this software will help exercise physiologists to optimize humans' health and improve their performance under heat stress. An idea of what other factors we can add in a scientific research and in a tool like PHS is to evaluate the effect of the dust in the atmosphere during prolonged exercise and how particles can affect human health and performance. Heat acclimation and specialized training before a race are efficient ways to increase human performance in a hot environment. In addition, this study that we conducted showed that the core and skin temperatures of athletes in real-world conditions were stable and that they did not suffer from heat-related illness or excessive increases in their body temperature. Half marathons (Falani and Ioannina) were 21.1 km with durations ranging from 1h 30 min to 2h 30 min (the time finishers), which means participants experience several changes in their body temperature that can affect their concentration in the race and require them to adjust quickly to the conditions (such as heat) in which they compete to perform at their best without injuries. From the findings of the research, we found that volunteers finished the race with sweat loss and fatigue from heat exposure. Their body weight before the race in Falani was between 70±20 kg and after the race it was estimated (from the opinions of the volunteers) to be 1-2 kg lower for each participant. This means that dehydration plays a major role in hot environments, and for that reason, people should drink enough water to perform in a race. Performing prolonged exercises in hot environments can generally lead to an excessive increase in the core body temperature, but the skin temperature in both half marathons was decreased for all athletes who participated. I believe that PHS software is just the start of what innovation and technology can do. To predict or face extreme environmental conditions, humanity must first measure its performance in such situations to better understand how the world can change and how we must adapt to it. Hot, cold, altitude, microgravity and scuba diving are extreme environments that can easily reach the limits of human behavior and performance. We must be ready for this by preparing people through simulations such as environmental physiology labs and tools like software/applications to gain a better understanding of the steps that must be taken in the future. Exercise endurance in adverse environmental conditions such as heat is a subject that needs a careful eye because heat exposure can cause heat stroke in humans, therefore, it is important to have the right clothing, water and devices/applications (e.g., the Kestrel 5400, the inReach mini flame, or a rugged outdoor smartwatch) to foresee and protect ourselves as much as possible. Heat stress in half marathons has challenges because in 21.1 km the weather can slightly or rapidly change based on factors such as air temperature, air velocity and humidity and humans have to be acclimatized to deal with this kind of condition so to avoid heat illness in hot environments. Generally, environmental physiology is a scientific field with many challenges and innovations, where people try to adjust to the environment they are facing with the minimum damage to their bodies. Simulations in environmental physiology labs or the usage of software such as PHS prepare people for what their bodies can handle under extreme weather conditions and how to improve their performance with the right training. Adverse environmental conditions bring us closer to the limits of human endurance, therefore we must always be organized and ensure safety with proper training and equipment. It is a challenge for a person to run a difficult race in a hot environment and succeed in the end, which gives him confidence and makes him mentally strong.

CHAPTER 6: CONCLUSION

This study aimed to measure, evaluate and predict the effects of heat stress on endurance races and how body temperature (skin and core) reacts to it. The measurements of core and skin temperature and the rate of credibility in the software "Predicted Heat Strain'' under heat stress were crucial because we examined the effects of adverse environmental conditions in these two half-marathons and how this can have an impact on human lives. The prediction of the volunteer's core temperature (PHS) was very close to the results from the real conditions in the race, indicating the reliability of the software. On the other hand, the prediction of the volunteer's skin temperature (PHS) was not close to the results from the real conditions. We can understand that PHS could have some improvements in the future to calculate the results of real conditions in skin temperature more correctly and accurately. The prediction of volunteer's temperature on these two half-marathons in a hot environment demonstrated that some results, such as skin temperature, are difficult to predict, and for that we should find better ways to improve tools (software or applications) such as PHS, so that we can have a better understanding and estimation of what to expect in extreme environments and how we can improve our performance.

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