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Effects of Environmental Conditions, Core Temperature, and Hydration Status on Women's Soccer Performance

Sean M. Collins[1], Abigail Poague[2], Robert Huggins[3] and Thomas G. Bowman[2]

[1]Exercise Physiology Department, University of Lynchburg, USA, [2]Athletic Training Department, University of Lynchburg, USA, [3]Korey Stringer Institute, University of Connecticut, USA

*Corresponding author: collins.s@lynchburg.edu

ABSTRACT

National Collegiate Athletics Association (NCAA) Division III athletes have restrictive rules on preseason practice timelines leading to questions about how performances are affected by environmental conditions during preseason practices.

Purpose: To determine how heat, humidity, core body temperature, hydration status, and reported sleep affected performances of women's Division III soccer players during preseason training.

Methods: Ten female collegiate soccer players (age=19.5±1.43 years, mass=62.14±5.01 kg, height=167.78±7.65 cm) were recruited. Core temperature was collected every 10 minutes during practice via an ingestible thermistor. Before each training session, participants recorded the previous night's sleep quantity and quality via the Karolinska Sleep Diary (KSD). Internal and external loads were monitored via heart rate, training load session rate of perceived exertion (TL-sRPE), and Global Position System (GPS) metrics. WetBulb Globe Temperature (WBGT) was continuously recorded throughout each training session, as well as participant total fluid consumption.

Results: TL-RPE, Δbody mass (ΔBM), ΔWBGT and maximum HR (maxHR) demonstrated approximately 53% of the variance in intensity (r=0.73, $F_{4,82}$=23.506, P<.001). Whereas sleep metrics, session duration, and average heart rate had no significant (p>0.05) impact on intensity.

Conclusion: The changes in exercise intensity observed were most affected by the perceived training load, body mass loss, heat indices, and maximum heart rate. These variables might need to be controlled to elicit the desired training outcome, while keeping player safety at the forefront during preseason soccer.

Keywords: Intensity, work rate, distance, external load, internal load

INTRODUCTION

Preseason collegiate soccer, especially at the Division III (DIII) level, creates unique challenges and increased performance demands for players. Taking place during the final weeks of August, with truncated timelines, the physiological load, and environmental stresses may impact training performance. During this period, players undergo multiple changes, including increased on-field training demands, new living and social situations, and different training environments, all of which can impact physiological and psychosocial stress[1]. Researchers and athletic trainers (ATs) have focused on environmental conditions during preseason training sessions as a primary risk factor for incidences of exertional heat illness (EHI)[2–4]. EHI risk stems from increased metabolic heat load and inadequate heat dissipation mechanisms, leading to the continued increase in core body temperature[2–4]. In response, primary heat dissipation mechanisms, cutaneous vasodilation, and sweating are activated

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to maintain a steady state and defend against heat-related illness during exercise. However, for these systems to function, adequate temperature gradients, between the surface of the skin and environment, are required[2]. However, during August preseason training periods in the northern hemisphere, wet bulb globe temperature (WBGT), which assesses overall heat stress, is typically elevated, thus impacting physiological responses and potentially impacting performance. Yet, current research has not provided a clear understanding of the impact of heat stress with an associated physiological response due to the lack of attention on NCAA DIII women's soccer.

For proper evaporative heat loss to occur beyond environmental gradients, an adequate sweat response is necessary[4–6]. Cooling requires an appropriate volume of sweat to be efficiently dispensed to the skin and to be efficiently evaporated for heat dissipation, which will lead to hypohydration if fluids and electrolytes are not adequately replaced. Excessive fluid loss can increase heat illness risk, due to an augmented evaporative heat sink response[6]. Expert consensus defined dehydration as >2% body mass loss per exercise session[5]. Travers et al.[7] and Périard et al.[8] have noted that dehydration increases cardiovascular strain, due to the reduction in plasma volume, resulting in difficulty sustaining blood pressure, cardiac output, and stroke volume, and may also result in decreased blood flow to skeletal muscle during exercise in warmer conditions, when compared to a euhydrated state. Therefore, increases in core body temperature and dehydration led to decreased levels of performance[9].

Similarly, the accumulation of training-induced internal and external load may also impact performance. External load, is typically, the physical work that occurs during an activity, like distance and speed, whereas internal load is representative of the physiological stress the body experiences[10]. Global positioning systems (GPS) units have become common to monitor the external load of field athletes, while measurements of heart rate, training load session rate of perceived exertion (TL-sRPE), and sleep quality have indicated levels of the internal load[11–13]. Physical work has a direct impact on the internal stressors, particularly the autonomic nervous system. Session RPE has specified the perception of training session difficulty, while sleep quality has provided information regarding how the physiological system is affected by training load, indicating the level of autonomic nervous system (ANS) activation[14]. Hyperactive ANS activity, due to training load, can result in an elevated physiological profile, which can augment performance[15,16].

As internal and external load accumulation has been shown to increase fatigue, this may lead to reductions in performance. Similarly, poor sleep has been shown to also impact academic and physical performances, where researchers have demonstrated that sleep score negatively correlated with mean power outputs, peak power outputs, and decreased time to exhaustion[12,17–19]. Further, given the external stress of training and the alteration in the psychosocial environment during the preseason, augmentation in sleep may be associated with changes in exercise performance, leading to increased rates of fatigue[1,18].

Individually, core temperature[20], hydration status[9], environmental conditions[6], heart rate[21], sleep quality[14], and external load[22] have been shown to impact performance, while remaining interconnected. Given the novel stresses of NCAA Division III preseason soccer, a need exists to examine the effects of core temperature, hydration status, environmental conditions, sleep, and physiological load together to more accurately understand these athlete performance changes. Therefore, the purpose of this study is to determine how WBGT, core body temperature, hydration status, and sleep affect the external load performance of women's DIII soccer players during preseason training. This study aimed to determine which factor or combination of factors had the greatest impact on preseason practice performance. Continued research on this population better prepares athletes, coaches, and sports medicine professionals working in similar conditions in the future to avoid potential athlete harm. Our findings from this study may be implemented in a manner that will make practices in hot, humid conditions safer for athletes.

METHODS

Subjects

Ten women's soccer players (age=19.5±1.43 years, mass=62.14±5.01 kg, height=167.78±7.65 cm), which consisted of 4 freshmen, 1 sophomore, 2 juniors, and 3 seniors were recruited from one NCAA DIII women's soccer team. Volunteers were excluded if they reported gastrointestinal (GI) disorders, as well as those self-reporting a history of

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heat illness. Additionally, members of the team with an injury existing before the start of the study were excluded from participation but were permitted to join once they were cleared by the athletic training staff for participation. Data collection occurred over 19 days at each practice (n=15), scrimmage (n=1), and games (n=3) for the duration of the preseason period. Before recruitment, the University of Lynchburg's Institutional Review Board (IRB) approval was obtained (LHS2122001) and participants received a description of the study in greater detail and had their questions answered verbally during individual pre-season meetings. Participants completed informed consent, demographics, and an athletics department health history questionnaire prior to participation in the study.

Design

External and internal loads were collected on soccer players (n=10) using global positioning system (GPS) units and heart rate (HR) monitors, respectively, during collegiate preseason practices (n=15), scrimmages (n=1), and games (n=3). Core temperature, WBGT changes, body mass changes (ΔBM), and rates of perceived exertion (RPEs) were tracked throughout these events as well to determine how they impacted training intensities.

Methodology

Before preseason practice began, participants' height was recorded using a portable stadiometer (Seca 21;3 Seca, Hamburg, Germany), nude body mass using a digital scale (WB-800S; Tanita, Tokyo, Japan) behind a privacy screen, and age (years). Participants also completed the Yo-Yo Intermittent Recovery Test (YYIRT), which estimated VO_{2max} (reliability = 0.71, validity = 0.75)[23]. After the completion of the YYIRT, participants began preseason practices. Throughout the season's practices, the coaching staff emphasized the importance of maintaining proper levels of hydration as well as maintaining a proper diet by recommending staying hydrated by regular consumption of fluids to thirst and eating a well-rounded diet, regularly.

Participants were assigned and wore back-mounted GPS devices (SPT2; Sports Performance Tracking, Melbourne, Australia) that provided workload details (distance traveled, work rate (m/min), and overall intensity (AU)). Intensity was assessed via a proprietary algorithm quantifying the sum total of movement distances and velocities over time. The GPS devices used 10-Hz and 100-Hz sampling rates for GPS and accelerometry, respectively, which are valid and reliable[11,24]. Chest-mounted Polar H9 (Polar, Bethpage, NY) heart rate monitors were worn to track heart rate, which was connected to the GPS units via Bluetooth. After practice, GPS data was downloaded to the Sports Performance Tracking cloud-based storage (GameTraka) where it was then trimmed to remove non-practice times, warm-up and cool-down periods from competitions.

During each day of data collection, participants followed the following procedures. Participants arrived at an exercise physiology lab 30 minutes before the start of practice, where nude mass was assessed. In this same lab, participants' water bottles were weighed using a bench scale (Ohaus Valor 1000 V12P6 (±0.001kg), Glendale, California) to determine total water consumption. Researchers instructed participants to completely empty their bottles before refilling during practice. Participants also provided details on their sleep quantity and quality from the previous night via scanning a QR code and completing a Google Form (Google, Mountain View, CA) of the Karolinska Sleep Diary (KSD). The KSD assessed how well participants slept, if there were difficulties falling asleep, if their sleep was restless, how deeply the individual slept, how much the individual dreamed, and if the individual felt that they got enough sleep[14]. Participants received ingestible sensors (HQ Inc, Palmetto, FL) the evening before each session and were instructed to ingest the sensor 6-8 hours before the next day's session to allow core body temperature readings using data recorders throughout training sessions[22].

One hour before the start of each data collection session, the Wet Bulb Globe Temperature (WBGT) Heat Stress Tracker and Weather Meter device (5400; Kestrel Instruments, Boothwyn, PA) was placed outside at the session's location to acclimate to outdoor conditions. WBGT was recorded on the field at intervals of 10 minutes throughout the entire session. Researchers recorded minimum, maximum, and calculated session averages for WBGT during every training session. Core temperature readings during training sessions were assessed between drills or when participants subbed out during scrimmages and games.

Following each session, participants' nude mass was assessed after toweling off. While participants were behind the privacy screen, participants

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provided a Rating of Perceived Exertion (RPE) for the session's practice on a pictorial 1-10 scale, which they had been familiarized with before testing, While participants were behind the privacy screen, participants provided a Rating of Perceived Exertion (RPE) for the session's practice on a pictorial 1-10 scale, which they had been familiarized with before testing. RPE scores were then multiplied by the duration of the session in minutes to determine the Training Load-session Rate of Perceived Exertion (TL-sRPE)[10,25,26]. Researchers also weighed participants' water bottles again and collected a post-practice core body temperature reading.

Statistical Analysis

A stepwise linear regression approach was used for data analysis via SPSS Statistics 28.0 (IBM, Armonk, NY). The dependent variable was intensity (AU), which measures the frequency, magnitude, and length of high-velocity movements during the performance. Independent variables included session average and maximum heart rates (bpm), session $WBGT_{avg}$ (°C), ΔWBGT, session change (Δ) in body mass (ΔBM; kg), session amount of water consumed (mL), session TL-RPE (AU), work rate (m/min), the number of minutes each participant slept the previous night, number of awakenings the participant experienced, sleep quality, if the participant felt refreshed upon waking, how calmly the participant slept, how much the participant slept throughout the indicated time, the participant's ease of waking, their ease of falling asleep, and the number of dreams the participant had. All of the sleep data, except for the number of minutes slept, was answered by the participants in the form of a Likert scale via the KSD. An alpha level of $P<.05$ a priori was selected.

RESULTS

TL-RPE, ΔBM, ΔWBGT, and maxHR explained approximately 53% of the variance in intensity (r=0.73, $F_{4,82}=23.506$, $P<.001$) (Table 1). TL-RPE ($P<.001$), ΔBM ($P<.001$), ΔWBGT ($P=0.010$), and maxHR ($P=0.013$) significantly contributed to the model. Excluded variables included sweat rate/hour ($P=0.766$), WBGTmax ($P=0.493$), sleep number of awakenings ($P=0.865$), sleep duration ($P=0.907$), sleep quality ($P=0.499$), sleep feeling refreshed ($P=0.360$), sleep calmness ($P=0.486$), sleep through allotted time ($P=0.490$), sleep ease of waking ($P=0.358$), sleep ease of falling asleep ($P=0.989$), sleep number of dreams ($P=0.249$), duration of the session ($P=0.684$), and average HR ($P=0.356$). Descriptive statistics, including 95% CIs, can be found in Table 2. Figures 1-4 show the effects of each significant independent variable on intensity with a trend line.

DISCUSSION

Previous research has demonstrated augmented physiological effects of exercising in hot and humid environments[5,7–9], the effects of hydration status[5,7,9], changes in heart rate, and core temperature[27] on performance, however, limited research has been conducted to determine the effects of TL-RPE, body mass change, and ΔWBGT on exercise intensity (AU) and workload in female soccer players, particularly during the preseason. Most studies to date concerning climate and exercise implications are completed on male and/or elite athletes[5,7–9,25,27]. Implementing load monitoring, via GPS, has empowered coaches and athletes to observe player loads in real-time while also allowing researchers to quantify performance and explore how environmental and psychosocial factors may impact performance[24]. The current researchers explored several factors to determine which had the greatest impact on female NCAA D-III soccer athletes' preseason performance and concluded that TL-RPE, ΔWBGT, maximum heart rate, and ΔBM have the greatest impact on player load, as assessed by intensity scores (AU).

Unsurprisingly, and similar to previous research, TL-sRPE was a significant influencing factor regarding intensity[22]. To quantify TL-sRPE, daily participant RPE scores (1-10) were multiplied by

Table 1. Stepwise Regression for Intensity (AU)*

	B	*t*	*p*	Δr^2
Constant	-3.641	-.488	.627	
TL-RPE (AU)	.022	5.401	<.001	.24
ΔBM (kg)	9.962	3.877	<.001	.14
MaxHR (bpm)	.147	2.539	.013	.06
ΔWBGT (°C)	-.742	-2.656	.010	.04

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Table 2. Descriptive Statistics

	Mean ± SD	95% CI Lower Bound	95% CI Upper Bound
Intensity	26.90±8.79	23.62	30.19
ΔBM (kg)	0.51±0.33	0.38	0.63
Sweat Rate (L/h)	0.73±0.35	0.59	0.85
TL-RPE (AU)	711.57±266.03	612.23	810.90
$WBGT_{max}$ (°C)	31.4±2.60	30.45	32.39
ΔWBGT (°C)	8.43±2.36	7.55	9.31
Sleep # Awakenings (AU)	0.67±1.06	0.27	1.06
Sleep Duration (minutes)	454.00±99.38	416.89	491.11
Sleep Quality (AU)	3.73±0.87	3.41	4.06
Sleep Refreshed (AU)	2.97±0.85	2.65	3.28
Sleep Calmness (AU)	4.03±0.89	3.70	4.37
Sleep Through Allotted Time (AU)	4.37±0.93	4.02	4.71
Sleep Ease of Waking (AU)	3.03±0.99	2.66	3.41
Sleep Ease of Falling Asleep (AU)	3.93±0.94	3.58	4.29
Sleep # of Dreams (AU)	1.97±1.42	1.43	2.50
Duration of Session (minutes)	123.90±14.17	118.61	129.19
HR Avg (bpm)	114.80±15.41	109.04	120.55
MaxHR (bpm)	119.96±15.88	114.02	125.88

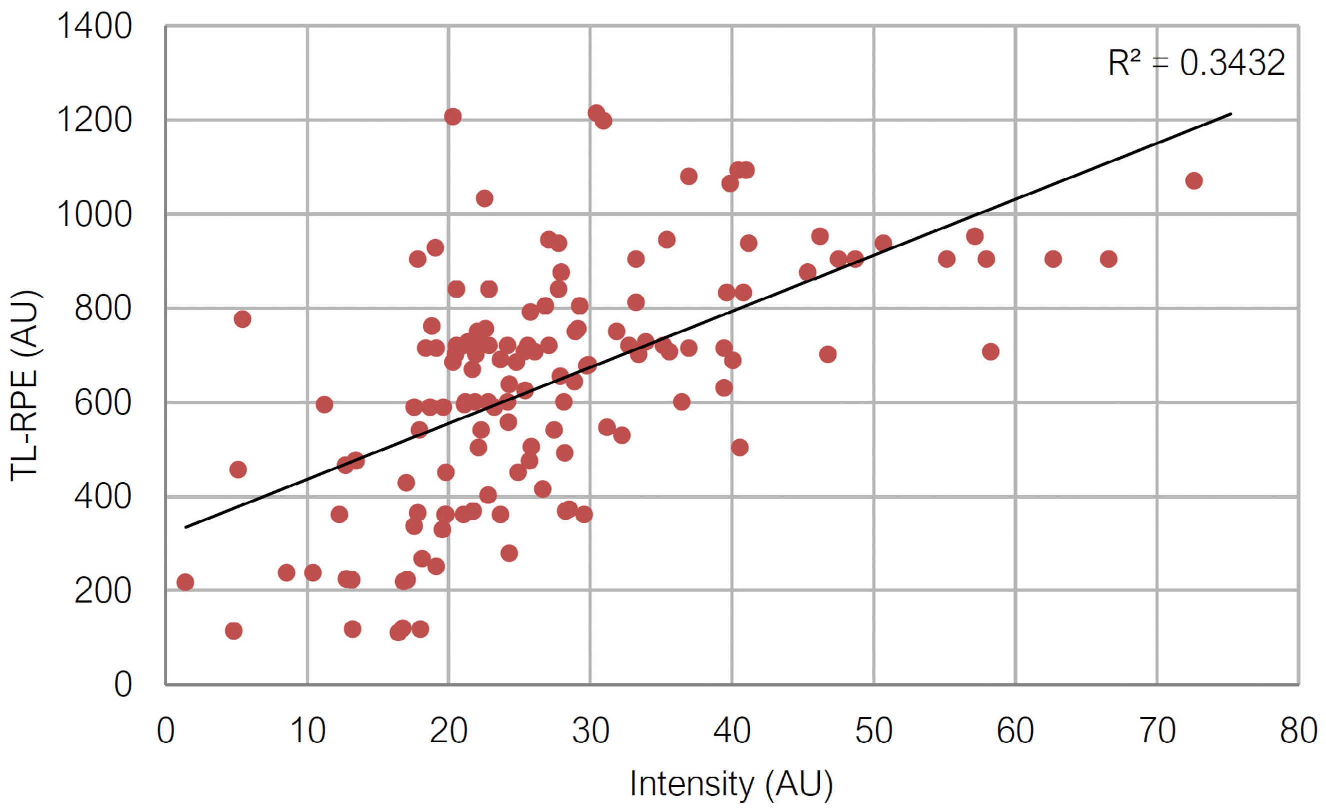

Figure 1. Scatter plot showing effects of TL-RPE on intensity

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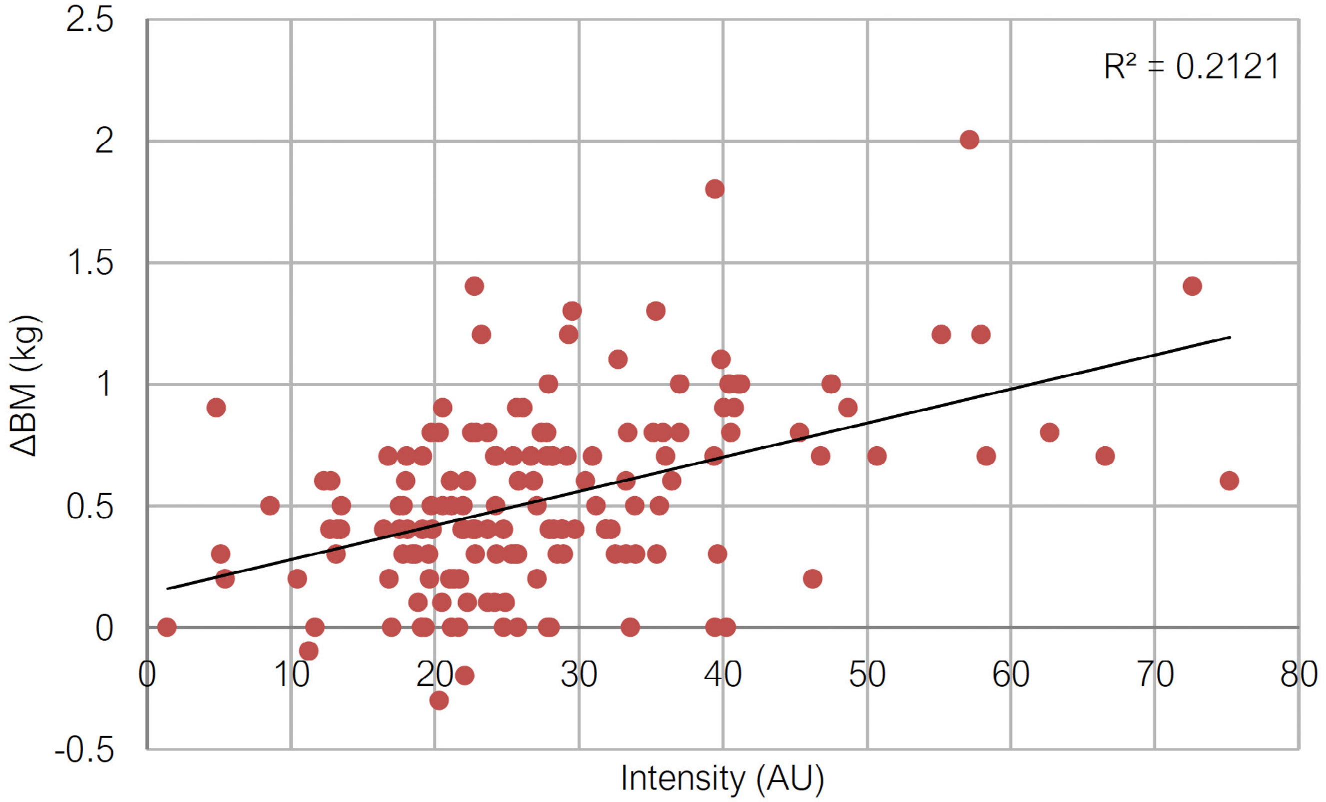

Figure 2. Scatter plot showing effects of ΔBM change on intensity

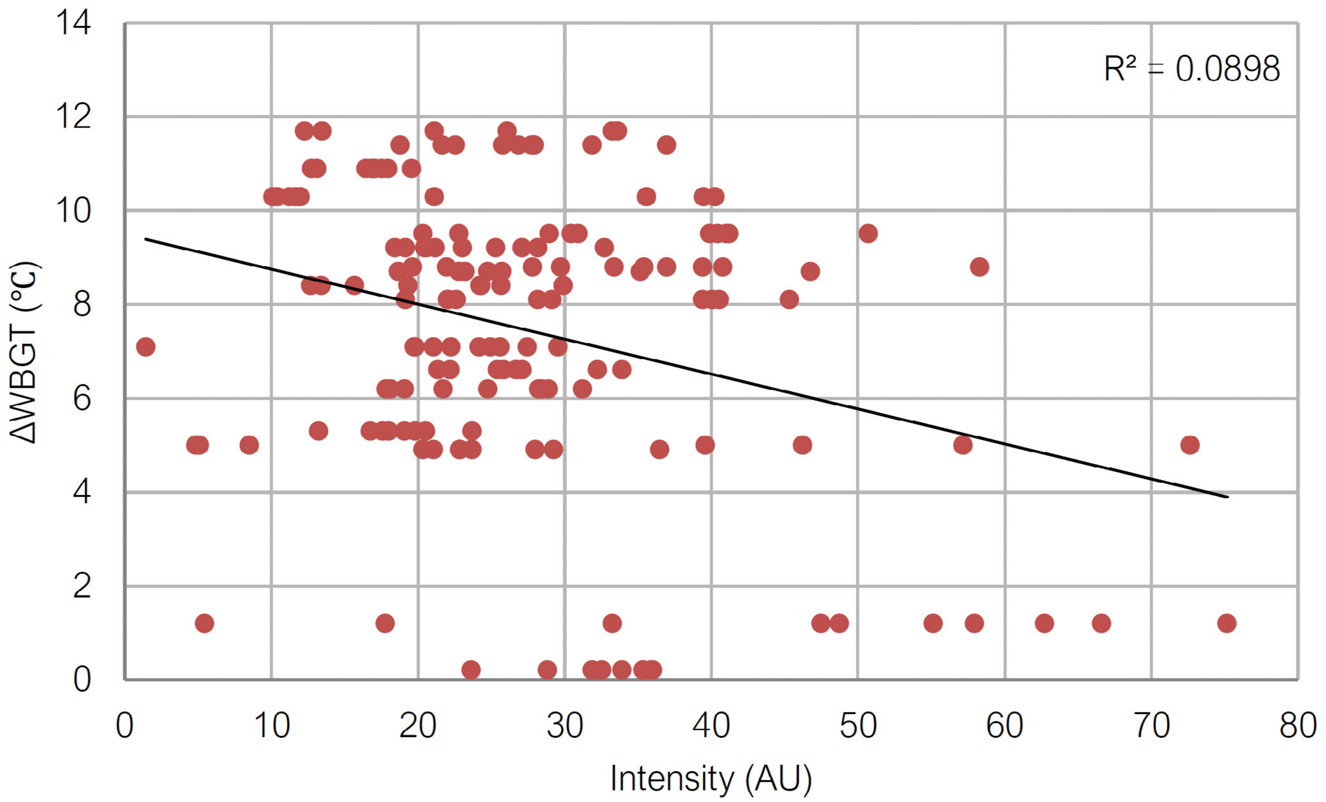

Figure 3. Scatter plot showing effects of ΔWBGT change on intensity

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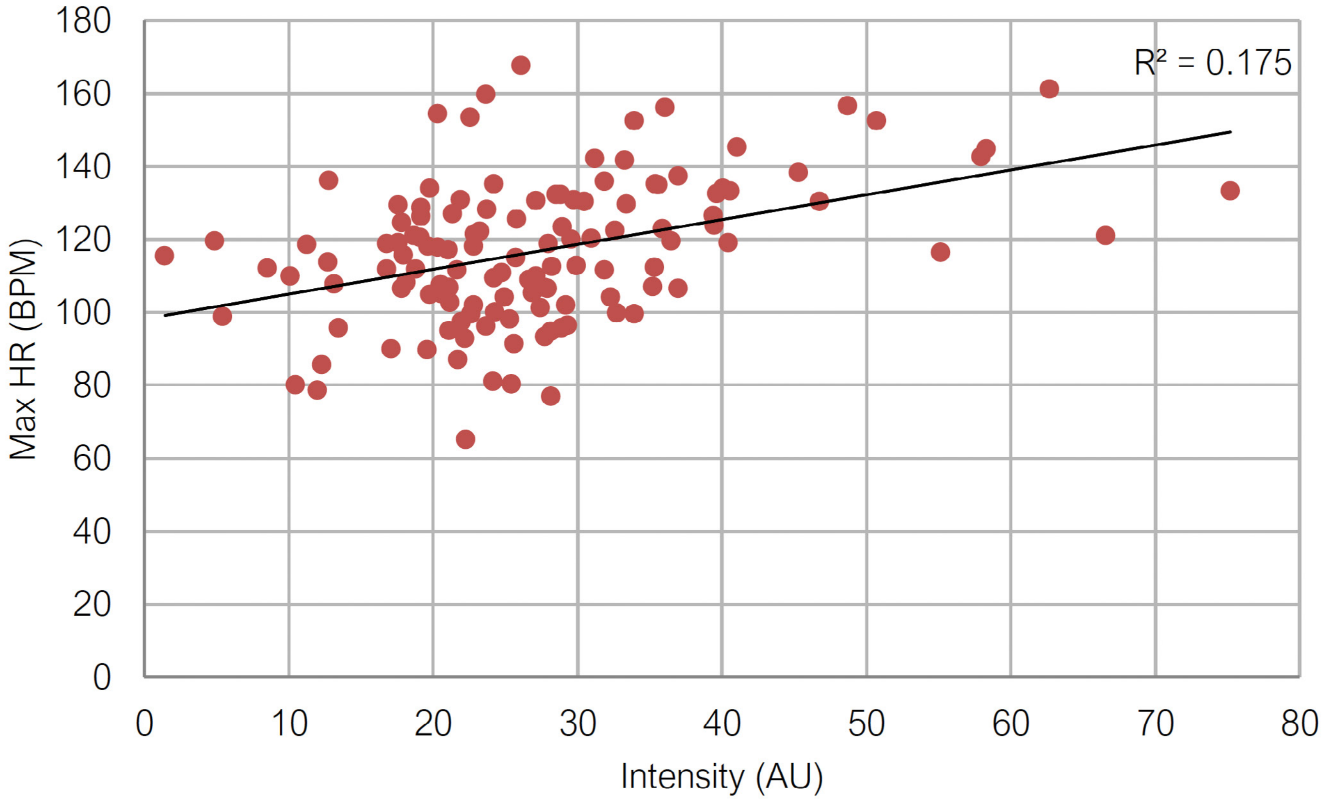

Figure 4. Scatter plot showing effects of maxHR on the intensity

session duration, indicating internal load[10,22,25,28]. Participants' ability to match RPE rating to physiological workload becomes more reliable over time yet still correlates with HR and intensity[21,28–30]. As was confirmed with TL-sRPE and max heart rate, respectively, being directly proportional to the intensity (Figures 1 and 4). It was also found that the average TL-sRPE was 711.57±266.03 AU, which is similar to those found in Division I (DI) in-season women's soccer athletes[22]. However, given the differences between in-season and pre-season training, this comparison may not provide an accurate representation of the similarity of DI to DIII TL. In regards to maxHR, this study found that the average was 119.96±15.88 bpm, which was lower than reported heart rates in other divisions[22,31]. The researchers speculate that the difference was due to the interval nature of preseason soccer training and the increased use of small-side games rather than full-field training and set-piece development, which is the traditional focus during in-season training and may account for increased workloads and higher average heart rates.

From a sleep perspective, this study failed to demonstrate a significant effect of sleep on pre-season performance. Previous research has shown that sleep duration and quality of sleep have a performance-based impact and athletes do typically report lower sleep efficiency and greater sleep fragmentation compared to sex and age-matched non-athletes[18,32]. When challenged via sleep deprivation, athlete performance results in a reduction in cycling performance[19], reduced reaction time[33], and reduced sprint and steady-state exercise pace[34]. However, these performance decrements were seen with significant sleep disturbances (~3hrs to 30 hrs), whereas the athletes here had minimal sleep-related issues. Their sleep performance scores (Table 2) show good sleep scores out of a possible 5-point Likert scale. Due to these scores, sleep does not seem to be an issue for these athletes at this point of the season, but may play more of a role as the season and semester progresses.

Additionally, hydration status has also been shown to impact on-field performance[27]. A commonly used method to track hydration levels involves pre- to post-practice body mass differences to determine the level of dehydration[3,7,8]. Unsurprisingly, the researchers found that increased ΔBM, likely due to the loss of body water via sweat, was associated with increased intensity during preseason training and was coupled with increased metabolic heat production. Based on these results, it is speculated that athletes who participated in this study did not consume enough water to offset body mass loss during training sessions, which is typical of field athletes[35]. Previous research

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has shown performance decreases with as little as 2% body mass loss[36]. Due to the increased workload, higher WBGTs, and increased intensity during the preseason, elevated dehydration rates may increase the risk for exertional heat stroke (EHS)[5]. Fluid intake was also tracked by weighing participants' water bottles pre and post-practice and asking for recall regarding the refill rate per bottle. Combined with ΔBM change, sweat rate (L/hr) was calculated, but was found not to explain the variance in practice intensity. The relationship of intensity to sweat rate versus total body mass change was surprising and contradicts a large body of pre-existing evidence regarding the effects of hydration status on performance[5].

Most studies to date appear to focus on $WBGT_{max}$ or $WBGT_{avg}$. To our knowledge, there is little or no research studying ΔWBGT from the beginning of the session to the end of the session and its effects on intensity. Understanding the potential effects of ΔWBGT on performance is crucial when structuring preseason practices to minimize physiological strain due to environmental conditions. Previous research has shown that as WBGT increases, athletes are unable to maintain higher intensities for extended periods[6]. Throughout preseason practices, the researchers found that the average ΔWBGT was 8.43±2.36 °C. Similar to previous research reporting hypothermic average WBGT environments, the ΔWBGT reported here was inversely related to intensity[27,37]. The rate in ΔWBGT occurred during practice resulted in decreased intensity but demonstrated the effect massive shifts in the environmental state during preseason practice in the mid-Atlantic region may impart strain on physiological mechanisms, resulting in a reduction in intensity. However, since preseason practice days are limited in DIII, acclimatization may not have occurred during the data collection window, and as training continued, the impact of ΔWBGT on performance may have been mitigated. Additionally, since ΔWBGT is more extreme during the early to middle afternoon, the ΔWBGT and intensity relationship may help guide practice planning. By moving practices to periods where $WBGT_{avg}$ and ΔWBGT over a practice period are lower may help alleviate dehydration and body temperature-related health concerns.

LIMITATIONS

While exercise and exercise intensity have been shown to impact sleep variables, such as overall sleep quality (AU), the researchers were unable to relate intensity (AU) to sleep metrics for this population[12]. These findings may be due to the nature of the preseason environment that allowed for adequate sleep focus, a reduced academic load, and a lower accumulated physiological load. Most other research assessing sleep and performance comparisons assesses acute performance metrics, i.e. power output (W), whereas the intensity metric using GPS for on-field soccer intensity was an algorithm assessing total work over a full practice period[12,38]. While exercise intensity can affect sympathetic and parasympathetic activation, resulting in disrupted sleep patterning, which can then impact future performance, the researchers were unable to document such an effect during this study.

Also, core temperature was initially a primary focus of this study, but it was found that core temperature fluctuations did not significantly impact intensity. To that end, a potential limitation of this study may be the technology utilized to measure and record core temperatures. Furthermore, while the research team instructed participants to ingest subsequent sensors 6-8 hours before the practice session only if the previous day's sensor had been passed, we cannot ensure with certainty that the given instructions were followed. Therefore, there is the possibility that core temperature readings were affected due to multiple sensors found within participants' GI tracts or sensors were not positioned properly to provide accurate core temperature readings. Another potential limitation may lie in tracking participants' water consumption via water bottle measurement and recall. A recall could have been inaccurate, which was the reason for measuring mass, however, since participants were required to arrive at pre-practice weigh-ins with a full water bottle to be weighed to measure water consumption throughout practice accurately they may have been partially full bottles or consumed water while waiting to be weighed in and were unable to fill bottles due to time constraints.

PRACTICAL APPLICATION

Training intensity is directly proportional to the perception of intensity (TL-sPRE), ΔBM, and maxHR while indirectly proportional to ΔWBGT over a practice period. From a training perspective understanding these relationships during a preseason training period can help coaches regulate workload and better target conditioning

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adaptations. From a clinical perspective, understanding the relationship between intensity and ΔBM can help make better decisions about practice monitoring, whereas ΔWBGT can also be considered as having an impact on the performance and potential risk for environmental stressors on the athletes. Furthermore, practices for the week should vary regarding intensity. Each day of practice should not be a high-intensity practice. Given the strong positive correlation between TL-sRPE and intensity, data might suggest that this may be a more cost-effective measure for those programs that are budget-limited. Lastly, environmental conditions should be monitored to ensure that a high-intensity practice is not taking place on a day with more straining environmental conditions.

Future research should focus on the relationship between environmental conditions, athlete external load, hydration, and physiological stress, especially in sports with short training camp times. More specifically, future research should aim to discern why change in WBGT as opposed to the maximum or average WBGT appeared to have the greatest impact on intensity and its impact on physiology.

CONCLUSION

Preseason NCAA DIII soccer is a period where players are challenged by increased training volume and intensity demands in conjunction with environmental stress in a short timeframe. These conditions impact player intensity. High internal stress, as determined by TL-sRPE and the greater reductions in body mass during events in conjunction with large short-term fluctuations in environmental conditions negatively impact player intensity. The combination of these factors should be considered during training periods to improve performance and mitigate fatigue. This can be accomplished by providing proper practice periodization to match environmental conditions in conjunction with allowing for appropriate hydration opportunities.

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CONFLICTS OF INTEREST

No potential conflict of interest was reported by the author(s).

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ETHICAL APPROVAL

Ethics for this study were approved in line with the University of Lynchburg's Institutional Review Board (IRB) (LHS2122001), participants also received a description of the study in greater detail and had their questions answered verbally during individual pre-season meetings. Participants completed informed consent, demographics, and an athletics department health history questionnaire prior to participation in the study.

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