Submitted: 25 August, 2023 Accepted: 19 September, 2023 Published: 30 December, 2023 DOI:10.22514/jomh.2023.127

JOMH
Journal of Men's Health

ORIGINAL RESEARCH

Effects of conditioning activities and time of day on male elite football players

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Abstract

This study evaluated the effects of different warm-up protocols based on conditioning activity combined with stretching exercises at different times of the day. Participants (20 first league of Tunisian football players) performed four warm-up protocols on two times a day in the morning: 09:00–10:00 and in the evening: 16:00–17:00, with at least 2 days between test sessions. All groups followed the warm-up randomly at two different periods of the day on non-consecutive days. The four protocols included: Dynamic stretching (DS), Dynamic stretching + conditioning activity (DS + High-Intensity Sprints HSJ), Dynamic stretching + drop jump (DS + DJ), and control (CONT). The thirty-meter sprint performance after different stretching and potentiation-based warm-up protocols was recorded. Two-way Permutational multivariate analysis of variance (PERMANOVA) analysis was applied to examine the difference between warm-up protocols, the difference between the time of day and the interaction effect. The major finding revealed that 30 m sprint results and the exercise-induced temperature significantly differed from morning and evening stretching and potentiation-based warm-up protocols (statistically significant $p < 0.05$, and evening measurements were higher compared to the morning). In conclusion, and from a practical point of view, if the objective is to increase performance over a shorter period of time, each of these warm-up protocols can be useful. For the best improvement, DS + HSJ may be preferable both in the morning and the evening.

Keywords

Chronobiology; Football; Post-activation potentiation; Time of day; Physical activity

1. Introduction

The warm-up is a crucial component of athletic preparation that has been consistently shown to enhance subsequent athletic performance [1–6]. Research has demonstrated that higher body temperature is associated with improved physical performance. A synthesis of numerous studies investigating the impact of temperature on sports performance suggests that there exists an optimal muscle temperature range for training and performance, typically between 31 °C (95 °F) and 37 °C (99 °F) [7–10]. A compelling example of this phenomenon is the daily cycle of body temperature, which typically reaches its highest point in the late afternoon [11–13]. Researchers argue that an active warm-up can enhance performance because it aligns with the natural diurnal temperature curve, which tends to correspond with increased muscular power [14–16]. In other words, a body with a higher temperature is better poised for optimal performance. There are several mechanisms that explain this performance enhancement, including increased muscle temperature, improved blood flow, and enhanced oxygen uptake [17, 18].

Post-Activation Potentiation (PAPE) has been recognized as a highly effective method for optimizing performance by stimulating the neuromuscular system. This phenomenon can significantly improve the execution of movements that require maximum voluntary effort, especially during the initial phase of swimming [19, 20]. Several studies have demonstrated that PAPE can be induced by submaximal and maximal external loads, such as back squats [21], lunges [22], eccentric flywheel exercises [22, 23], and the utilization of specialized equipment like the Resilience Rack [24], all of which have shown potential for positively impacting swimming start performance. Conversely, certain resistance protocols, such as those involving hand paddles and parachutes [25], have not yielded improvements in swimming start performance.

Recent attention has been drawn to the acute enhancement of performance through the induction of Post-Activation Performance Enhancement (PAPE). PAPE is triggered by preceding muscular activity [26] and is defined as a physiological phenomenon that significantly enhances immediate muscle performance, such as jumping and throwing, following a conditioning activity (CA). This CA can involve a single high-intensity exercise or a series of continuous movements, including individual resistance exercises [26]. In practice, PAPE can be achieved through CA with a wide range of external loads, ranging from 70% of an individual's one-repetition maximum (1RM) [26] to even higher loads, up to 110–130% of 1RM [27]. Additionally, factors such as training experience [28], individual strength levels [20], and the specific muscle groups engaged in the activity can influence the magnitude of subsequent performance improvements. While previous research has primarily focused on rapid changes in power output and movement velocity during explosive activities like jumping and throwing immediately following various CAs, limited attention has been given to investigating the potential effects of PAPE on locomotion.

Furthermore, the effectiveness of PAPE has been well-established in resistance exercises that approach muscle failure. It is not solely determined by the total work performed but also by the capacity to maintain a heightened level of movement speed and power output. The deceleration of a barbell during specific exercise sets is acknowledged as a reliable indicator of neuromuscular fatigue [29]. Nevertheless, as of now, no research has undertaken a simultaneous examination of power output, which could provide valuable insights into how PAPE impacts changes in training volume and bar speed. For instance, Beato [30] reported that PAPE can manifest in notable improvements, such as a significant enhancement in countermovement jump (CMJ) performance within 3–7 minutes, aligning with findings from prior research [31]. Additionally, Maroto-Izquierdo *et al*. [32], observed that an eccentric overload resistance intervention produced a similar PAPE effect, albeit with a longer duration than previously documented. To date, there is limited evidence examining the duration of PAPE using intermittent approaches [33], and only a few studies have delineated the optimal timeframe for harnessing PAPE in the training strategies of elite male sprinters.

The term Post-Activation Potentiation (PAP) was formerly employed to describe performance enhancements following a Conditioning Activity (CA). However, recent literature has discerned differences and introduced the distinct terms PAP and PAPE [34, 35]. Post-Activation Enhancements encompass a comprehensive array of performance enhancements, encompassing those elicited almost immediately following CA, including electronically induced convulsive responses [35]. As an alternative approach, PAPE focuses on the enhancement of voluntary contractions, notably strength, after a CA [35]. One of the primary mechanisms underlying PAP is phosphorylation of the regulatory light chain of the myosin head [36], along with changes in muscle pennation angle [33]. However, it remains uncertain whether these mechanisms of PAP also impact PAPE [34]. Conversely, the principal mechanisms driving PAPE encompass increased recruitment of higher motor units [36] and augmented muscle perfusion [34]. While prior studies have delved into the fundamental mechanisms of both PAP and PAPE [37], a substantial body of literature has traditionally ascribed performance improvements after CA solely to the development of strength, often disregarding any preceding warm-up activities [38, 39]. In light of current research, we will assess changes in voluntary contractions following CA, specifically in terms of jump performance, and henceforth employ the term PAPE [40, 41].

PAPE is a phenomenon that results from the preactivation of muscle using a conditioning activity with a higher load before performing a training session or competition [42, 43]. This preactivation results in increased phosphorylation of myosin regulatory light chains and improved alpha-motoneuron excitability [44]. The Vector Theory [45] also highlights the importance of biomechanical similarities between the conditioning and target activities for potentiation. Four variables that impact the effectiveness of the conditioning activity are intensity, volume, resting time, and movement similarity. Intensity activates the working mechanisms [44], while volume is inversely proportional to intensity. Resting time is directly conditioned by intensity and volume [46] and movement similarity is also important [47].

The majority of investigations centered on harnessing the PAPE phenomenon have incorporated substantial loading (ranging from 75% to 95% of the 1 repetition maximum) as the preparatory stimulus [48, 49]; certain researchers have additionally advocated for the integration of maximal isometric conditioning contractions [28, 50].

Specifically, the functioning of physiological and neurobiological processes relies upon the inherent biological rhythms present within the human body, which are commonly referred to as circadian or diurnal rhythms [51]. This phenomenon has been comprehensively documented and elucidated through research investigations that delve into the impact of time-of-day on diverse outcome measures [52–54]. The effects stemming from temporal fluctuations in resistance exercise, encompassing facets such as muscle strength, power, and sprint capabilities, span a range from 3% to 21.2%. These variations are contingent upon factors such as the individual under examination, muscle group engagement, and the experimental framework. Earlier researchers have extended the preparatory warm-up prior to time trial events in swimming [55] and cycling [56] with the intent of elevating morning body temperature to align with afternoon levels, thereby potentially enhancing morning performances. However, the insights gleaned from these inquiries suggest that disparities in performance attributed to time-of-day disparities are unlikely to be primarily mediated by alterations in body temperature. In contrast, Bernard *et al*. [57] (1998) noted a synchronization between daily fluctuations in anaerobic performance and changes in core temperature, while Racinais *et al*. [58] (2004) reported that an inactive warm-up regimen designed to elevate morning temperature to afternoon levels attenuated the diurnal variance in muscle power by augmenting morning muscle contractility.

Within the context of PAPE protocols, the diurnal fluctuation assumes considerable significance as well. The responsiveness of muscle tissue to volitional or electrically induced stimuli is subject to modulation by its contractile history. Evident in this regard is fatigue, which constitutes a conspicuous manifestation of contractile history, manifested as the muscle's inability to elicit an anticipated magnitude of force generation; and this fatigue component exhibits dependency on the temporal phase of the day. Although a restricted number of investigations have delved into the ramifications of PAPE on diurnal variability, it is an area of emerging importance warranting further exploration [55, 59, 60].

Gaining knowledge of methods to improve sprinting can lead to more efficient training and result in improved sprint performance among elite soccer players. The purpose of this study was to assess if a PAPE warm-up protocol may increase sprint ability in elite soccer players either in the morning and afternoon. Therefore, the aim of this study was two hypotheses: (1) to analyze the effects of different PAPE protocols on the performance of elite football players during sprint performance and (2) to identify the possible interactions of PAPE protocols and sprint performances with the time of the day.

2. Materials and methods

2.1 Participants

The G*power software (Version 3.1.9.4, University of Kiel, Kiel, Germany) was used to determine a priori the sample size in the study [61]. With a type I error (alpha) of 0.05, a statistical power (1-beta) of 0.80 and an effect size (η^2p) of 0.25, at least 10 participants would be required for the study should be included in the study for total sample size using a two-way ANOVA with repeated measures [62]. Due to the risk of football players leaving, twenty-five participants were recruited. Because they did not complete all the required sessions. There were several reasons for this reduction. Some participants cited a lack of time, motivation, or resources as their reasons for discontinuing their participation. Others experienced unwanted side effects or dissatisfaction with the treatments. Additionally, scheduling conflicts posed a challenge, as some participants could not attend morning sessions due to their academic commitments. Five of the original football players (n = 5) were disqualified from the data analysis. Therefore, twenty elite soccer players club competing in the first league of the Tunisian Soccer League (Tunisian Professional League) with training scheduled five times per week for 80 to 120 min per session that was exclusively held during the evening. (age: 20 ± 1.1 years; body mass: 82 ± 15.8 kg; body height: 184 ± 8.7 cm) with ≥3 years of training and national competition experience were recruited for the study. The sports season was in Spring phase and the club's name is Tunisian stadium.

Oral temperature was meticulously recorded through the use of a digital clinical thermometer (Omron, Paris, France), known for its precision of 0.05 °C. These temperature measurements were acquired at the initiation of each testing session subsequent to a 15-minute period where subjects maintained a supine position, and also subsequent to the implementation of each distinct warm-up protocol. To mitigate potential sources of interference, explicit instructions concerning sleep patterns and dietary intake were provided to the participants prior to the onset of the experiment. While the customary body temperature baseline is conventionally defined as 37 °C (98.6 °F), it is essential to acknowledge the considerable variance present within this metric. For individuals classified as normothermic, the mean daily temperature can deviate by as much as 0.5 °C (0.9 °F), with daily oscillations potentially spanning between 0.25 to 0.5 °C. The nadir of the body's temperature pattern typically transpires at approximately 4 AM, while the acme is reached around 6 PM. This circadian pattern remains remarkably steady on an individual basis and remains impervious to instances of fever or hypothermia. However, prolonged shifts in the rhythm of daytime sleep and nighttime wakefulness can elicit a responsive recalibration in the circadian temperature rhythm [63]. The axillary temperature usually records a reduction of approximately 0.55 °C (1.0 °F) compared to the oral temperature. Elevating both the duration and caliber of sleep has been established to promote enhancements in performance within the athlete population, spanning diverse disciplines aligned with the unique demands of their individual sporting endeavors [64].

While the conventional norm for body temperature rests at 37 °C (98.6 °F), it is imperative to acknowledge the substantial range of variability that exists. Among individuals classified as normothermic, the average daily temperature may diverge by approximately 0.5 °C (0.9 °F), with daily fluctuations potentially extending from 0.25 to 0.5 °C. The nadir of the body's temperature pattern is typically observed around 4 AM, while the zenith is reached approximately at 6 PM. This circadian pattern remains notably consistent on an individual level and remains unperturbed by episodes of fever or hypothermia. Prolonged modifications in the transition between daytime sleep and nocturnal wakefulness cycles induce an adaptive recalibration in the circadian temperature rhythm [63]. The axillary temperature typically registers approximately 0.55 °C (1.0 °F) lower than the oral temperature. Enhancing both the duration and quality of sleep has been demonstrated to facilitate performance improvements among athletes across various domains pertinent to the specific requirements of their respective sports [64].

During the night prior to each testing session, participants were instructed to adhere to their customary sleep routines. Additionally, subjects were enjoined to sustain their typical level of physical engagement and to abstain from engaging in high-intensity physical training for a period of 24 hours prior to the testing. This precautionary measure was implemented to forestall the potential impact of lingering fatigue on test performance, ensuring that residual exhaustion would not compromise the results. Before the start of the study, all of the participants were provided with comprehensive information describing the aim of the study, the nature of the research being conducted, and the experimental design. After that, they signed the informed consent form. Since at least a year ago, each athlete has made it a point to incorporate resistance training into their regimen at least twice per week. The study was carried out 14 days following the conclusion of the national championship. The participants, who donated their time, were given comprehensive information about the scope, goal, and methodology of the study prior to the start of the investigation. The subject signed an informed consent form to confirm their willingness to participate in the study. Additionally, all of the research complied with the internationally recognized standards for the ethical investigation of human biological rhythms [65]. Before their scheduled testing sessions, study participants were advised to acquire at least eight hours of sleep every night. Additionally, they were told to eat something at least two hours before the morning and evening sessions in order to arrive with a full stomach. Throughout the implementation and testing phases of the protocols, the participants were duly educated regarding the importance of abstaining from high-intensity physical exertion, as well as refraining from the consumption of substances such as alcohol and caffeine, due to their potential influence on the study outcomes [66].

2.2 Procedure

2.2.1 Familiarization session

The familiarization session, conducted three days prior to the main test session, played a pivotal role in ensuring that participants were well-prepared and acquainted with the various aspects of the study. This session aimed to familiarize participants with the warm-up modalities, sprinting techniques, and the overall testing procedures. Participants were introduced to each warm-up modality. This included a 5-minute warm-up period, primarily consisting of jogging, to raise their heart rates and prepare their bodies for physical exertion. Following the jogging warm-up, a 7-minute session of dynamic stretching was conducted to enhance flexibility and mobility. Detailed explanations of the testing methods and procedures were provided to participants during this session. They were briefed on how each aspect of the study would be carried out, ensuring they had a clear understanding of what to expect during the main test session. In addition to the warm-up and testing procedures, participants' body stature and mass were measured. This included height and weight measurements to establish baseline data for each participant. The warm-up protocol for the familiarization session mirrored that of the actual test session, comprising the 5-minute jogging warm-up, dynamic stretching, and two minutes of rest before each modality. The session concluded with a 30-meter sprint test. Each participant performed three trials of the sprint test, with a 30-second rest interval between each trial. The best performance from these trials was recorded for subsequent analysis. The familiarization session aimed to ensure that participants were not only physically prepared but also well-informed about the study's procedures, which ultimately contributed to the accuracy and reliability of the data collected during the main test session.

This research study revolved around the implementation of three distinct warm-up protocols and a control protocol. All groups followed the warm-up randomly at two different periods of the day on non-consecutive days. The study consisted of 4 sessions, subjects were randomly assigned in a counterbalanced manner to either perform the Dynamic Stretching (DS), DS with added High-Intensity Sprints (HSJ 85% 1RM), DS with added Depth Jumps (DJ), and a Control (CON) scenario routine before performing 30-meter sprint performance. These evaluations took place across two discrete time intervals within a single day, with a minimum of two days separating each interval. Following each 30-meter sprint test, a recovery period of 1 minute was observed, adhering to established guidelines [67]. The entirety of these protocols was administered in a randomized and counterbalanced sequence, spanning a span of 3 weeks. The testing procedures were executed within the same outdoor locations where the football players routinely engage in training and competitive activities. The schematic representation of the research's experimental design is visually elucidated in the accompanying flowchart (Fig. 1).

2.2.2 PAPE protocols

Dynamic Stretching protocol (DS): dynamic stretches include five exercises that focus on major muscle groups as 30 s work 30 s rest [68]. The exercises were performed in the following order: plantar flexors, hip extensors, hamstrings, hip flexors, and quadriceps femur [68, 69]. The duration of dynamic stretching was approximately 7 minutes in each protocol, with the exception of the control protocol. The track running exercises consist of 5 exercises and the participants performed 2 sets of 5 exercises over a distance of 10 meters (total 100 meters) and a minute of rest was added between the sets.

Dynamic Stretching + Half Squat protocol (DS + HSJ): after DS protocols, HSJ protocol was performed. In the HSJ protocol (85% 1RM), subjects performed 2 sets of 4 repetitions of half squats with a 5-minute rest interval between sets. To determine participants' 85% of half squat performance, the participants performed 10 maximum repetitions (10-RM) tests in the session without specific warm-up. 10-RM was converted to 1 max rep (1MT) using Brzycki [70] equations.

$$1\,MT = (Weight\,lifted/(1.0278 - [0.0278 \times Repeats])$$

After specific warm-ups of different intensities, 5 minutes of passive rest was performed before 1RM. This rest period was determined by considering the results of Willardson and Burkett [71] and Rahimi's [72] studies in which the effect of resting at different times on squat performance increased more after 5 minutes of rest.

Dynamic Stretching + Drop Jump (DS + DJ): The drop jump (DJ) protocol involved the execution of 2 sets, each comprising 6 repetitions of jumps, with a resting interval of 2 minutes interposed between sets. The entirety of this supplementary protocol was concluded within a 5-minute timeframe. To execute the DJ protocol, the participants initiated by stepping off a 30 cm box and subsequently performed a countermovement jump. This necessitated a sequential flexion of their hip, knee, and ankle joints during the eccentric phase, followed by the extension of these joints during the concentric phase, facilitating a rapid and forceful jump while exerting maximal effort [73]. With the intention of refining the stretch–shortening cycle and capitalizing on momentum generation during the concentric phase, participants were directed to "expeditiously disengage from the ground and execute a jump of maximal attainable height" [74].

Control (CNT) Protocol: The control protocol consisted of a 5-minute warm-up session (jogging), followed by 7 minutes

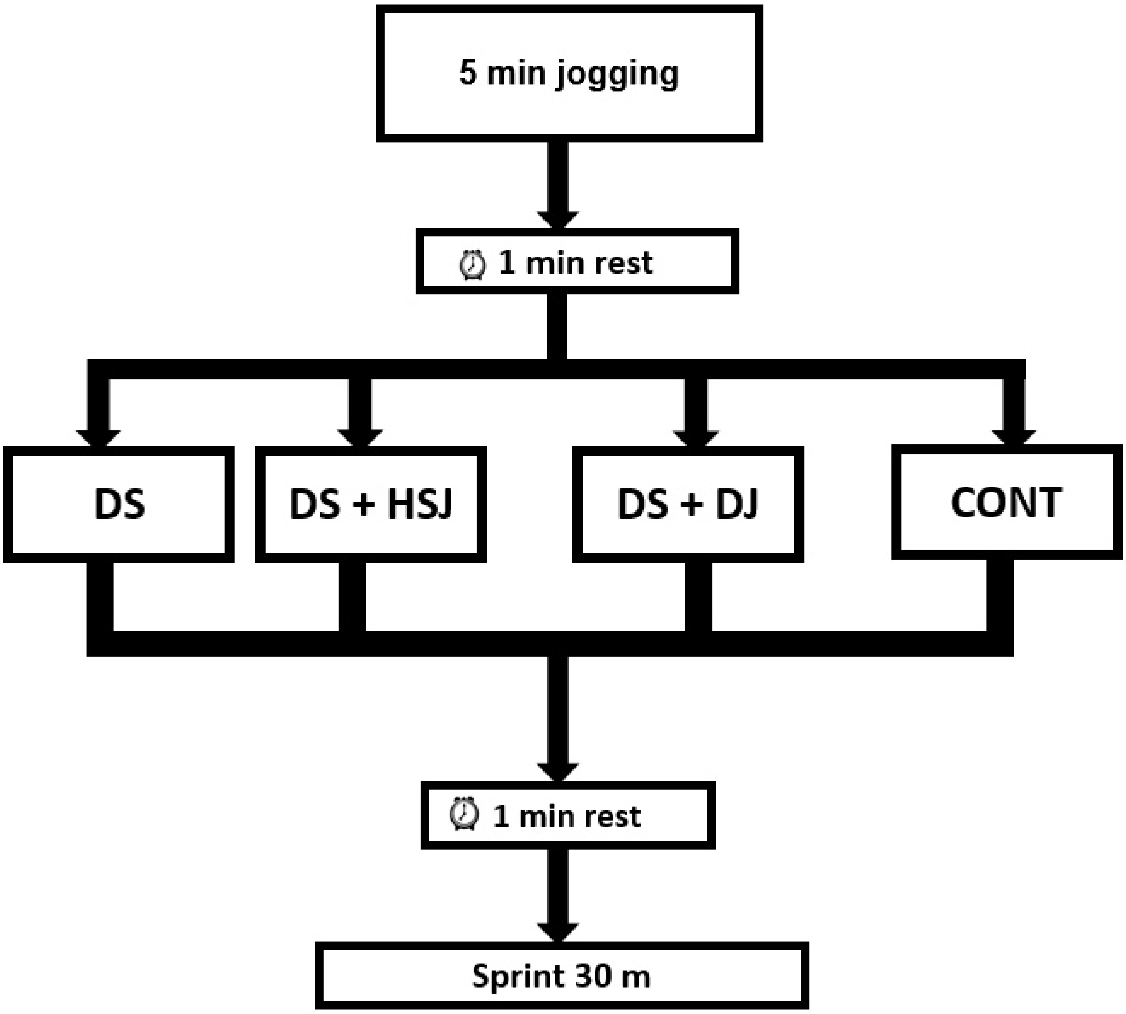


FIGURE 1. The flow chart for experimental design of research. HSJ: Half squat jump; DJ: Drop jump; DS: dynamic stretching; CONT: control.

of dynamic stretching. A 2-minute rest period preceded each modality, and the protocol concluded with a 30-meter sprint test.

2.2.3 Anthropometric measurements

Participants' body weights were assessed through employment of an electronic scale (Tanita SC-330S, Amsterdam, Netherlands), boasting a precision of 0.1 kilograms (kg). The stature of each participant was measured utilizing a stadiometer (Seca 213, Seca GmbH & Co KG, Hamburg, Germany) with an accuracy level of 0.01 meters (m) during the measurement procedure [75].

2.2.4 30 m sprint test

A digital timer synchronized with two photocells was affixed at hip level to facilitate the sprint test procedure. After a resting interval of 1 minute following the completion of the warm-up protocols, participants were positioned 70 centimeters ahead of the designated starting line. The initial timing gates, spanning a range of 0.5 to 5 meters from the commencement point, were installed on separate tripods situated at heights of 1.00 to 1.20 meters above the ground. Subsequently, the remaining timing gates, extending between distances of 10 to 40 meters from the starting line, were positioned at heights of 1.30 to 1.50 meters above the ground. The sprint evaluation encompassed a distance of 30 meters and was conducted with the specific objective of ascertaining sprint performance duration [76]. The 30 m results of the participants were determined. For this study, sprint testing was conducted using Newtest Powertimer 300 series test equipment (Tyrnava, Finland).

2.3 The statistical analysis of data

In this investigation, the assumption of univariate normal distribution for quantitative data was examined using the Shapiro-Wilk test, and the assumption of multivariate normal distribution was examined using the Henze-Zirkler test. Normally distributed quantitative data were summarized as mean ± standard deviation. Quantitative data that do not show normal distribution are shown as median-interquartile range (IQR) together with the Box and Whiskers graph. Since the multivariate analysis assumptions for the groups could not be provided (Multivariate normal distribution and homogeneity of variances assumptions), two-way PERMANOVA (Permutational Analysis of Variance) analysis with Euclidean distance as a similarity matrix was used to examine the difference within groups, the difference between groups and the interaction effect (Permutation N = 9999). Partial omega-squares ($\omega^2{}_p$) were computed to assess the extent of the effect observed between different groups. To gauge the magnitude of differences, the standardized effect size (ES) was employed, adhering to predetermined thresholds: 0–0.059 denoting a small effect, 0.06–0.14 indicating a medium effect, and $\geq$0.15 signifying a large effect [77]. The threshold for significance was set at $p < 0.05$. American Psychological Association (APA) 6.0 style was used to report statistical differences. Data Analyzes were performed using Python 3.9 (Centrum Wiskunde & Informatica, Amsterdam, Netherlands), and Graphpad Prism. v8.0 (Insightful Science, San Diego, CA, USA).

3. Results

There was a significant difference (F = 399.71; $p < 0.001$; $\omega^2{}_p$: 0.93; large effect) between the warm-up protocols when exercise-induced 30 m sprint performance was presented in Fig. 2. *Post-hoc* analyses showed that the difference between DS—DS + HSJ, DS—DS + DJ, DS—CONT, DS + HSJ—CONT and DS + DJ—CONT warm-up protocols was statistically significant ($p < 0.001$). The best improvement was observed in the DS + HSJ protocol. However, there was no statistically significant difference between DS + HSJ and DS + DJ ($p > 0.05$). A statistically significant difference was found in terms of time effect for 30 m sprint performance (F = 535.39; $p < 0.001$; $\omega^2{}_p$: 0.89; large effect) and the results improved significantly in the evening compared to the morning. The time * protocol interaction effect was also statistically significant (F = 23.12; $p < 0.001$; $\omega^2{}_p$: 0.51; large effect).

Fig. 3 shows the protocols exercise-induced temperature (°C) before potentiation regimens at varying intensities in the morning and evening. There was significant difference between the warm-up protocols (F = 1883.80; $p < 0.001$; $\omega^2{}_p$: 0.74; large effect). *Post-hoc* analyses showed that the difference between DS—DS + HSJ ($p < 0.001$), DS—DS + DJ (p = 0.02), DS + HSJ—CONT ($p < 0.001$), and DS + DJ—CONT (p = 0.004) before potentiation protocols was statistically significant. However, there was no statistically significant difference between DS—CONT ($p > 0.05$) and DS + HSJ—DS + DJ ($p > 0.05$) before potentiation protocols. A statistically significant difference was found in terms of time effect for temperature (°C) before potentiation protocols (F = 15.918; $p < 0.001$; $\omega^2{}_p$: 0.38; large effect). The time * protocol interaction effect was also statistically significant before potentiation protocols (F = 139.52; $p < 0.001$; $\omega^2{}_p$: 0.12; medium effect).

The warm-up protocol differences in exercise-induced temperature (°C) after morning and evening potentiation procedures are illustrated in Fig. 4. There was significant difference between the warm-up protocols (F = 2271.60; $p < 0.001$; $\omega^2{}_p$: 0.78; large effect). *Post-hoc* analyses showed that the difference between DS—DS + HSJ ($p < 0.001$), DS—DS + DJ (p = 0.004), DS + HSJ—DS + DJ (p = 0.007), DS + HSJ—CONT ($p < 0.001$), and DS + DJ—CONT ($p < 0.001$) after potentiation protocols was statistically significant. However, there was no statistically significant difference between DS—CONT ($p >$ 0.05) after potentiation protocols. A statistically significant difference was found in terms of time effect for temperature (°C) after potentiation protocols (F = 17,808; $p < 0.001$; $\omega^2{}_p$: 0.44; large effect). The time * protocol interaction effect was also statistically significant after potentiation protocols (F = 126.22; $p < 0.001$; $\omega^2{}_p$: 0.19; large effect).

4. Discussion

The aim of this study was to analyze the differences in 30 m sprint performance (sec) assessed at two different times of day (morning and evening) after various stretching and potentiation-based warm-up protocols (DS, DS + HSJ, DS + DJ and CONT).

The major finding of the present study revealed that measurements of 30 m sprint performance (sec) were significant differences to morning and evening stretching and potentiation-based warm-up protocols. The difference between DS—DS + HSJ, DS—DS + DJ, DS—CONT, DS + HSJ—CONT and DS + DJ—CONT were statistically significant.

The football players' 30 m sprint performance was the best in DS + HSJ group. This result suggests that the DS + HSJ protocols used by the football players will have a favorable impact on their 30 m sprint performance (sec) results. We found that the 30 m sprint performance of the football players increased significantly in evening. In addition, the time * stretching and potentiation-based warm-up protocols interaction effect was also statistically significant for 30 m sprint performance. Our findings showed that performing DS + HSJ protocols in the evening hours will maximize 30 m sprint performance. The results of the present study revealed that measurements of exercise-induced temperature (°C) were significant before and after potentiation protocols at different intensities in the morning and evening. Also, for both before and after potentiation protocols the temperature (°C) was significantly higher in the evening than in the morning. The interaction results showed that the DS + HSJ in the evening hours protocols maximized the 30 m sprint performance, before and after the strengthening protocols the temperature (°C) of the football players.

Irrespective of the specific warm-up protocol employed, the outcomes of this study unveiled a noteworthy increase in Upper-Body Force Time (UFT) scores for both a + b and the total scores during the early evening hours in contrast to the morning. The uniqueness of our findings is underscored by the dearth of prior research investigating the impact of time of day on UFT performance among judo athletes. Conversely, existing studies have delved into the influence of different time periods on various performance metrics within the realm of judo athletes. For instance, as reported by Chtourou *et al.* [78], the repeated sprint running performance and mood of elite athletes subjected to examination did not exhibit a discernible correlation with the time of day during which the test was conducted. The rationale provided for this observation was associated with the practice of early morning training sessions, as reported in their findings [78]. In a study by Chtourou *et al.* [79], an examination was conducted to explore the influence of diurnal variations on short-term maximum performances prior to and following a judo match among youthful judo athletes.

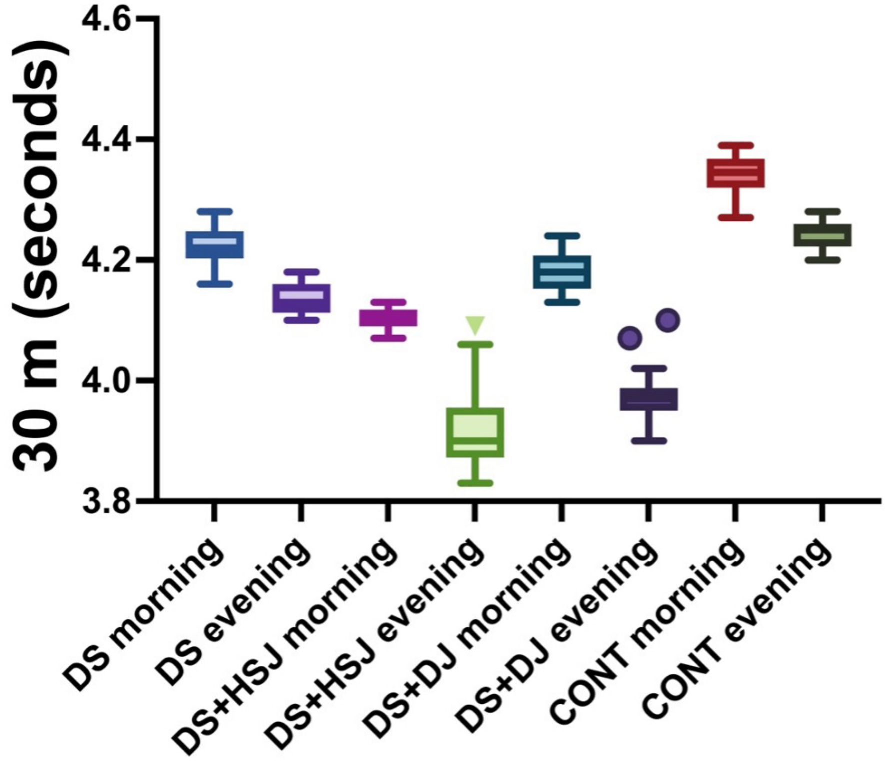


FIGURE 2. Thirty meters (sec) sprint results in different potentiation protocols in the morning and evening (Box-and-Whisker Plot). DS: dynamic stretching; HSJ: Half squat jump; DJ: Drop jump; CONT: control.

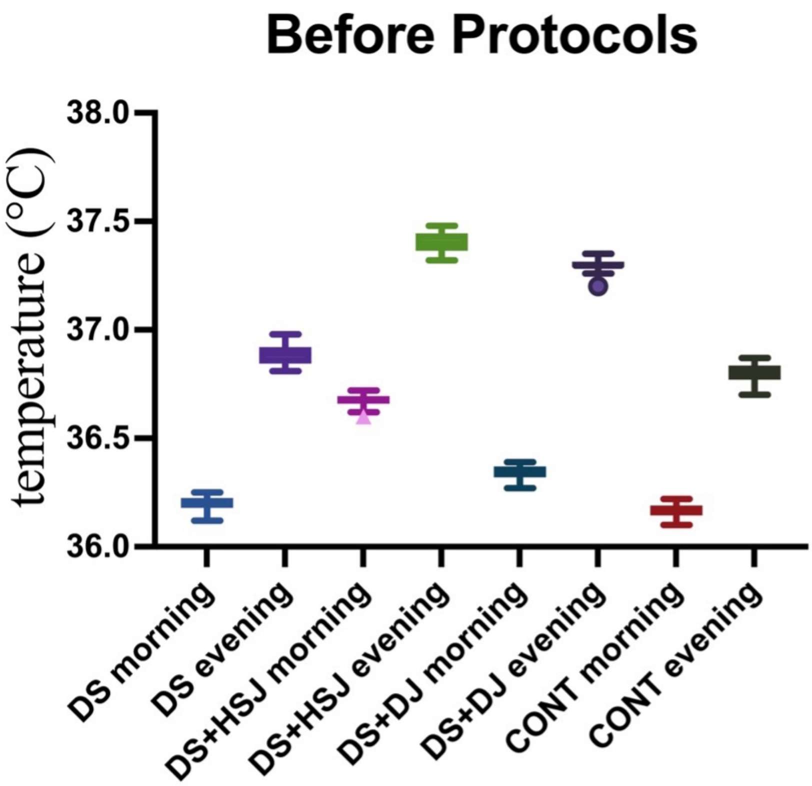
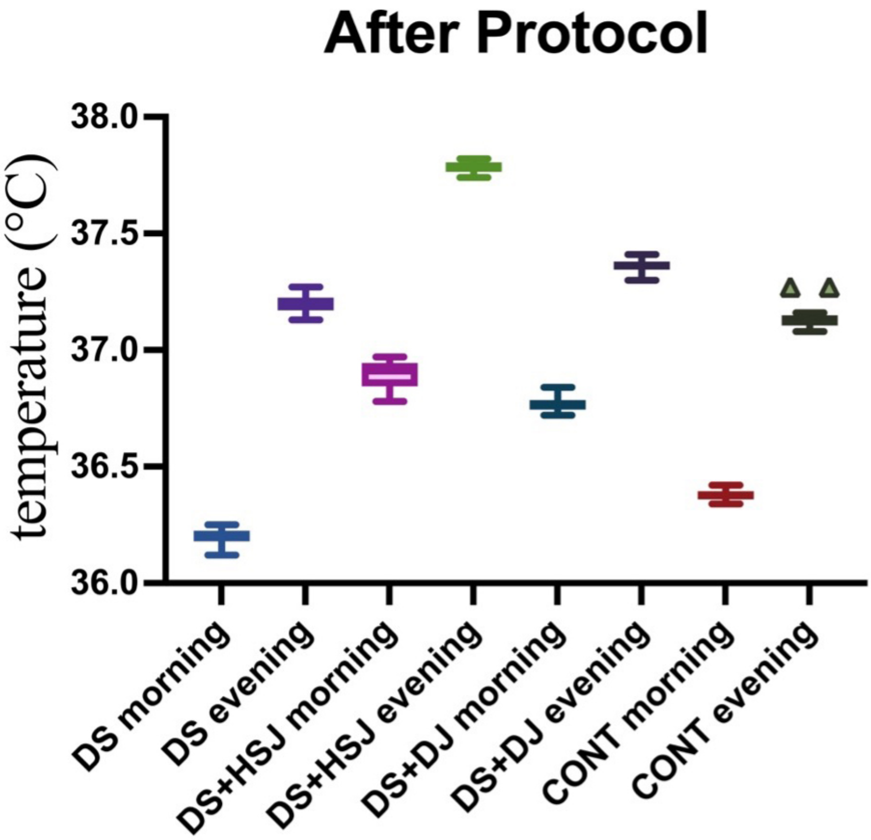


FIGURE 3. Averages of 30 m sprint performance before potentiation protocols at different intensities in the morning and evening. CONT: control; DS: dynamic stretching; HSJ: Half squat jump; DJ: Drop jump.



F I G U R E 4. Averages of temperature (°C) after potentiation protocols at different intensities in the morning and evening. CONT: control; DS: dynamic stretching; HSJ: Half squat jump; DJ: Drop jump.

The research outcomes elucidated that the afternoon period exhibited notably heightened muscle strength and power levels among the judo athletes in comparison to their morning counterparts [79].

Some studies did not find any improvement on 30 m sprint performance after PAPE protocols [80]. Lim *et al.* [80], examined the effects of 3 types of postactivation potentiation (PAPE) protocols (single-joint isometric, multijoint isometric and multijoint dynamic) on subsequent 10-m, 20-m and 30-m sprint performance in 12 well-trained male track athletes. They found no differences in sprint performance among the 4 protocols at 10-m, 20-m or 30-m intervals [80]. The findings of this study differ from the findings of our study. It also differs from our study in terms of its methodological design and the parameters measured. Furthermore, this study did not investigate diurnal variation. Some studies in the literature suggest that 30 m sprint performance may increase after PAPE protocols [81–84]. The findings of these studies share similarities with the results of our study. In the study conducted by Fernández-Galván *et al.* [85], the results indicated that both one set of seven repetitions of HT at 60% of 1RM and one set of seven repetitions of complete squats at 60% 1RM were effective in improving various performance measures. The HT protocol led to substantial improvements in the 5 m test, maximum power, and maximal ratio of horizontal-to-result force. Meanwhile, the complete squat protocol resulted in substantial improvements in the 5 m test, 10 m test, maximum theoretical force, maximum power, and maximal ratio of horizontal-to-result force. These results suggest that both protocols could be effective in enhancing performance, but it is important to consider the specific goals and individual characteristics of the athletes when selecting the appropriate PAPE protocol [85]. Anthony *et al.* [84] investigated the effect of alternate-leg bounding on sprint acceleration. They found that sprint acceleration performance improved following plyometric training by allowing sufficient recuperation between these activities; nevertheless, they reported that the benefits may vary depending on whether an additional load is added [84]. Tsimachidis *et al.* [83] investigated the effect of a 10-week mixed resistance/sprint training program on the post-activation potentiation of sprint performance before to, between and after strength training sessions. They found that post-activation potentiation was observed in the combined training group during the last training session of the intervention for both the 0–10 and 0–30 m sprint [83]. The research conducted by Bevan *et al.* [81] (2010) sought to establish the impact that PAPE has on the sprint performance of professional rugby players. There was no noticeable temporal effect that took place over the course of the investigation with regard to the times that were achieved in the 5-meter and 10-meter sprints. Nevertheless, when the individual reactions to PAPE were taken into consideration, a significant improvement in sprint performance was observed over both 5 and 10 meters in comparison to the baseline sprint. This improvement was noticeable despite the difference in distance. Turki *et al.* [82] investigated the effects of different warm-up active dynamic stretching volumes on the performance of 10- and 20-meter sprints. A significant main effect for the pre-post measurement, the dynamic stretching condition, and an interaction effect were seen for the 0- to 20-m sprint time [82]. Dello Iacono and Seitz [86] examined the effect of two PAPE protocols based on the Barbell Hip Thrust with a load of 85 percent and the ideal load for power development on soccer players' sprinting speed. After applying a 4-minute and 8-minute recovery period in both PAPE regimens, a significant increase in speed was observed across the board [86]. Our results are consistent with previous studies that dynamic stretching alone is sufficient to provide the potentiation of sprint performance compared to the control protocol without additional activity [81, 82, 87]. The results of this study were similar to our study likely because of the increased muscle-tendon stiffness and the changes in muscle morphology [88]. These findings can be attributed to short-term neuromechanical adaptations, such as an increase in muscle-tendon stiffness [62]. The effects of post-activation potentiation (PAPE) depend on the balance between neuromuscular fatigue and muscle exhaustion [36]. The outcome of this balance is determined by the load being used, as reported by Sale (2004) [50].

These findings underscore that PAPE has been observed to adversely affect pre-Conditioning Activity (CA) countermovement jump (CMJ) performance [89–91] in the absence of proper preparatory exercises. Two studies, both utilizing short warm-up sessions of only 4 and 5 cycles at 70 watts for a brief duration or a sprint warm-up, concluded that while there was an improvement in sprint performance attributable to PAPE, questions remain regarding whether CA could have been enhanced by alternative assumptions, such as performance improvements stemming from the general mechanisms of warm-up [89–91]. Contrary to this, Tobin and Delahunt [89] reported that a CA involving 40 plyometric jumps significantly increased CMJ height and peak force at all posttest time points. Notably, this finding suggested that pre-CMJ performance optimization may no longer necessitate inclusion of the aerobic component within the warm-up routine [89, 92]. In this context, Young and Elliott [92] posited that, while augmented musculotendinous compliance could lead to enhanced storage and release of elastic energy, a stiffer system might ensure a minimal delay between the stretching and shortening phases of a stretch-shortening cycle (SSC) [92]. This, in turn, could result in improved explosive performance, which is imperative in rapid SSC events lasting less than 250 ms, such as sprinting (*e.g.*, Usain Bolt's sprinting contact time of 86 ms [93]). Consequently, Maloney *et al.* [94] suggested that a stiffer system may indeed augment power-related activities but cautioned that performance gains could be limited once an athlete reaches their optimal stiffness threshold, beyond which performance may be compromised [94].

One argument supporting the utilization of plyometric exercises to induce PAPE lies in their ease of application in pre-competitive scenarios, as compared to heavy resistance exercises which demand more time or specialized equipment [84, 94, 95]. The plyometric protocol employed in this study requires no equipment and can be readily performed in common spaces, both indoor and outdoor. This further underscores the practicality of such an approach, with performance improvements of approximately 4% observed in the absence of additional equipment.

Moreover, it is important to recognize that sports performance, such as in football, is not solely governed by physical factors encompassing physiological and biomechanical aspects. Cognitive and tactical factors, as well as psychological variables, play significant roles [96].

An inherent constraint within the current study pertains to its ecological authenticity. The induction of post-activation potentiation (PAPE) was achieved by having soccer players perform explosive squats at their maximal voluntary velocity. However, several challenges, encompassing logistical intricacies and safety considerations, arise when endeavoring to integrate such practices prior to matches. Ensuring safety often necessitates the involvement of qualified personnel, a feasibility that could be intricate, particularly in amateur clubs characterized by a limited ratio of strength and conditioning coaches to players. Consequently, forthcoming investigations should strive to establish PAPE strategies that align more closely with the real-world warm-up conditions preceding soccer competitive matches. This could involve the incorporation of plyometric exercises or analogous body-weight drills that underscore soccer-specific actions, thus enhancing the ecological validity of the findings. Moreover, a recent investigation conducted by Gołaś *et al.* [44] emphasized the necessity of tailoring the recuperation period between conditioning exercises and the specific explosive motor performance under consideration, and muscle fiber composition. Consequently, addressing this variable becomes imperative in forthcoming research endeavors, aiming to establish precise recovery durations that cater to players participating at diverse competitive tiers.

There are some limitations of this study. The study primarily focused on the effects of warm-up protocols on 30-meter sprint performance and exercise-induced temperature changes. Other relevant variables, such as agility, muscle function, or injury risk, were not explored. A more comprehensive assessment of athletic performance could yield a more holistic understanding. The study measured immediate performance effects after warm-up protocols. Long-term effects or how these protocols might impact performance during actual competitions or training sessions over an extended period were not investigated. Future research could explore the sustained effects of different warm-up strategies. Acknowledging these limitations is essential for the research community and practitioners to interpret the study's findings appropriately and to guide future research endeavors. Additionally, addressing these limitations can contribute to the development of more robust and applicable warm-up protocols for athletes across various sports and performance levels.

5. Conclusions

The present study revealed that there was a time of day effect on sprint performance. According to that, a statistically significant difference was found in terms of time effect for 30 m sprint performance and the results improved significantly in the evening compared to the morning. Increased in the early evening hours compared to the morning hours. In addition, the

30 m sprint performance (sec) results of football players who perform the DS + HSJ protocol can be better when compared to the results of football players who perform alternative PAPE protocols (DS, DS + DJ and CON).

The practical utility of the study contributes valuable insights to the realm of sports performance optimization. By capitalizing on the observed time-of-day effect and prioritizing the DS + HSJ protocol, coaches and athletes can enhance sprint performance and potentially gain a competitive edge in sports like football. However, it's important to acknowledge individual variability and consider these findings as part of a holistic training approach tailored to the specific needs and goals of each athlete. Future research might be aimed at enhancing different performance results of these types of PAPE protocols.

6. Limits of the study and future directions of investigation

The examination of warm-up protocols exclusively during morning and evening time slots neglects potential performance variations throughout the day. The omission of data from other time intervals diminishes a comprehensive understanding of circadian influences on performance outcomes. The study's concentration on the immediate effects of warm-up protocols on 30 m sprint performance precludes an assessment of the longitudinal impacts on broader aspects of athletic performance, injury prevention, and training adaptations over extended periods. The exclusive reliance on 30 m sprint performance as the sole outcome measure overlooks potential effects of the warm-up protocols on other key aspects of athletic prowess, including agility, endurance, and sport-specific skill execution.

Prospective studies could delve into the longitudinal implications of diverse warm-up protocols, exploring sustained performance enhancements, injury mitigation, and holistic athlete development over extended training periods. Future research endeavors could scrutinize the influence of individualized circadian rhythms on the interplay between warm-up protocols and diurnal performance variations, shedding light on the intricate interplay between internal timing and external interventions. Inclusivity can be broadened by encompassing female athletes in subsequent investigations, permitting the evaluation of potential gender-specific variances in warm-up protocol responsiveness and diurnal performance fluctuations.

In summary, the present study's intrinsic limitations underscore the necessity for expansive, in-depth future investigations. To furnish a more nuanced comprehension of the implications of warm-up protocols and time-of-day dynamics, a diversified participant pool, augmented physiological scrutiny, and broader performance evaluations are imperative. These directions hold promise for advancing the empirical foundations underpinning the practical implications of the observed effects.

AVAILABILITY OF DATA AND MATERIALS

Data are available for research purposes upon reasonable request to the corresponding author.

AUTHOR CONTRIBUTIONS

GBM and NS—perform the conceptualization; perform the validation; performs the project administration. ÖE, GBM and NS—perform the methodology; perform the investigation. ÖE and FHY—perform the formal analysis. GBM—perform the data curation. ÖE, GBM, GB, FHY and NS—perform the writing-original draft preparation. ÖE, GBM, GB, LPA, SBAM, FHY and NS—perform the writing-review and editing. NS—perform the supervision. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Inonu University (Approval number: 2023/4317). Informed consent was obtained from all subjects agreed to participate in this study.

ACKNOWLEDGMENT

Not applicable.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest. Georgian Badicu is serving as one of the Editorial Board members of this journal. We declare that Georgian Badicu had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to DM.

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How to cite this article: Ghazwa Ben Maaouia, Özgür Eken, Fatma Hilal Yagin, Georgian Badicu, Sameer Badri Al-Mhanna, Luca Paolo Ardigò, *et al*. Effects of conditioning activities and time of day on male elite football players. Journal of Men's Health. 2023; 19(12): 31-43. doi: 10.22514/jomh.2023.127.