

Optimizing pre-match preparation: Impact of four warm-up protocols on yo-yo IR2 and sprint performance in youth footballers

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Abstract

Problem Statement: Warm-up routines are crucial for enhancing athletic performance and minimizing injury risk, particularly in sports that involve explosive movements, such as soccer. Although various traditional and innovative warm-up strategies have been studied, there is a lack of systematic comparison among multiple protocols that integrate equipment such as foam rollers, resistance bands, and other balancing equipment to evaluate their effects on key performance measures in young athletes. **Approach:** This study employed a randomized crossover experimental design to investigate the effects of four distinct warm-up protocols on sprint performance (10 and 30 m) and endurance (Yo-Yo Intermittent Recovery Test Level 2) in 20 male elite U17 football players from the Greek National League. Each 30-minute protocol includes combined activation exercises, dynamic movements, resistance drills, and sport-specific activities to analyze their relative effectiveness. We conduct performance tests following a standardised 15-minute rest period, simulating pre-match conditions. **Purpose:** This research aimed to evaluate how distinct warm-up strategies affect short-term sprint and endurance performance, providing evidence-based recommendations for optimizing pre-match preparation in youth football. **Results:** Analysis revealed no significant differences in Yo-Yo IR2 performance across the four protocols ($p = .957$). However, significant differences were observed in 10 m ($p = .000$) and 30 m sprint times ($p = .000$). Protocol 1 (activation warm-up with foam rollers, resistance bands, BOSU ball, and football-specific drills) and Protocol 2 (dynamic warm-up and football-specific drills) yielded superior performance in sprint times compared to protocols involving higher resistance loading (Protocols 3 and 4), which negatively impacted sprint outcomes, likely due to increased muscle fatigue. **Conclusions:** Dynamic and activation-based warm-up routines that balance neuromuscular activation and fatigue appear more effective for optimizing sprint performance without compromising endurance. In contrast, warm-ups emphasizing resistance-based exercises may impair short-term explosive performance due to fatigue-related mechanisms. Coaches and practitioners should carefully tailor warm-up routines to match sport-specific demands while minimizing pre-competition fatigue, particularly in youth athletes.

Keywords: pre-match warm-up strategies, post-activation performance enhancement, youth soccer training, resistance-based warm-up, neuromuscular activation

Introduction

Warm-up routines are essential components of sports training and match preparation, particularly in high-intensity and intermittent sports such as football. A well-structured warm-up protocol not only increases heart rate and body temperature but also accelerates blood flow to working muscles, enhances joint mobility, and prepares the athlete both physically and mentally for exertion (Bishop, 2003; Smith, 2018; Anderson & Williams, 2020).

In recent years, traditional warm-up methods, such as light jogging and dynamic stretching, have been scientifically validated for their effectiveness in enhancing performance and reducing the risk of injury (Taylor et al., 2020). However, advancements in sports science have introduced modern strategies that incorporate equipment like foam rollers, resistance bands, and balance tools (e.g., BOSU balls). These strategies not only activate specific muscle groups and improve neuromuscular control but also engage physiological mechanisms such as the Stretch-Shortening Cycle (SSC), which is fundamental for explosive movements like sprinting and jumping (Smith & Brown, 2021).

Current studies have highlighted the benefits of activation-based approaches, utilizing the post-activation performance enhancement (PAPE) mechanism, particularly for achieving short-term strength gains and enhancing neuromuscular activation. Nevertheless, due to their high intensity, resistance-based warm-ups may also lead to premature fatigue or a reduction in SSC efficiency (Johnson et al., 2020). Additionally, whether such protocols can achieve similar performance outcomes with lower energy expenditure remains a topic of ongoing debate.

Despite growing interest, comparative research on warm-up protocols remains limited, particularly among elite youth athletes (Afroundeh et al., 2024). Most studies focus on isolated variables such as vertical jump or sprint performance, with less attention given to endurance-based measures like the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) (Buchheit & Laursen, 2013; Silva et al., 2024). Moreover, coaches and performance practitioners often face uncertainty in structuring matchday preparations due to inconsistent findings and heterogeneous testing protocols reported in the literature (Silva et al., 2024).

This study aims to address this gap by investigating the following research question:

How do four different warm-up protocols affect sprint and Yo-Yo endurance performance in elite youth football players?

To explore this question, the study was based on two initial protocols: a traditional routine commonly used in football, and a modern protocol designed to achieve similar performance with reduced energy cost. Subsequently, two additional protocols incorporating resistance-based activation exercises were developed, utilizing the PAPE mechanism. In total, four distinct warm-up protocols were implemented and evaluated.

The research employed a randomized repeated-measures experimental design, in which each player completed all four warm-up protocols on separate occasions, followed by sprint tests (10 and 30 m) and the Yo-Yo IR1 test. The findings are expected to contribute to evidence-based recommendations for optimizing pre-match warm-up strategies and promoting individualized, performance-oriented approaches in elite youth football.

Material and methods

Participants

The study engaged 20 male athletes who were actively participating on a football team within the Greek U-17 National Football League. All participants possessed a minimum of ten years of training experience. Each athlete attended five training sessions per week and participated in one official match each week. We conducted the present study using a single team to ensure the reliability of the findings and to evaluate the effects of the training programs effectively. We specifically selected healthy and injury-free athletes for the study sample. In addition, we obtained written informed consent from the parents of all participants.

The mean demographic characteristics of the participants were as follows: mean age = 16.25 ± 0.43 years, mean height = 175.1 ± 4.69 cm, mean body mass = 64.45 ± 6.14 kg, mean body mass index (BMI) = 20.99 ± 1.53 kg/m², and mean body fat percentage = $7.51 \pm 2.35\%$.

Procedures

A crossover experimental design was employed in this study to examine the effects of different warm-up protocols on performance. The study was conducted over four consecutive days with a sample of 20 participants, with 24-hour intervals between each testing day. Four different pre-match warm-up protocols, each lasting 30 minutes, were implemented. The applied protocols were conducted based on standard methods for assessing training load and physical performance, following controlled and consistent procedures. The literature indicates that maintaining stable environmental conditions and conducting measurements at fixed times increases the reliability of performance outcomes (Impellizzeri et al., 2004). Data collected during the study were analyzed by methodologies applied in similar research (Buchheit & Laursen, 2013).

Participants were divided into two groups of 10 individuals each. On the first day, Group 1 performed Protocol 1, while Group 2 performed Protocol 2. On the second day, the groups switched protocols. On the third day, Group 1 performed Protocol 3, while Group 2 performed Protocol 4. On the fourth and final day, the groups again switched protocols. This arrangement was designed to minimize the impact of external factors, including humidity, temperature, and wind, on the test results. All tests were conducted at the same time each day, on the same field, under consistent environmental conditions, and with participants wearing identical clothing (Impellizzeri et al., 2004; Foster et al., 2017).

Each participant completed a questionnaire to assess their physical condition and wellness status before and after the training, and they were instructed to complete it. Following the completion of the warm-up protocols, a 15-minute interval was implemented to simulate the conditions between warm-up and kick-off in an official match. All tests were initiated exactly 15 minutes after the warm-up to replicate the environment of an official game.

After this waiting period, the participants performed 10-meter and 30-meter sprint tests. Immediately following the sprint tests, participants completed the Yo-Yo Intermittent Recovery Test Level 2 (Yo-Yo IR2).

10 and 30 m speed test

To determine the 10-30 meter speed test values of football players, we tested the participants on the grass field with the help of a photocell. The football players began measuring as soon as they felt ready to start the sprint in the designated section, one meter behind the photocell (BX700-DFR-T AUTONICS). The measurements began when the football player crossed the speed line and ended when he stopped the photocell at the end of the 10-30 meter distance. We ask football players to sprint at maximum effort, completing two repetitions with one minute of passive rest in between. Speed test results are measured in seconds and milliseconds, highlighting the best performances achieved.

Yo-Yo Intermittent Recovery Test 2

The Yo-Yo Endurance level test is prepared for athletes with a better training level compared to the Level 1 test. During the test, athletes run at increasing speeds over a 20-meter distance. The starting speed for the Yo-Yo Endurance Level 2 Endurance Test, which has a rest area of 5 meters (rest period for 10 seconds) after 20 meters, is 13 km /h. Yo-Yo Endurance level 2 test was applied as follows: The football player started from the starting line and ran a 2x20-meter track between the starting line, return line, and finish line at an increasing speed determined by the sound signals coming from the CD. Between consecutive runs, participants took a 10-second active break, which involved completing a 2x5-meter run. This break commenced upon the participant crossing the finish line and required them to run a distance of 5 meters behind the finish line around a funnel before returning to the finish line to initiate the next track. The distance traveled was recorded as the final result when the participant successfully reached the finish line within the specified time on two consecutive occasions.

Daily Wellness Questionnaire (Fig.1)

The Daily Wellness Questionnaire is a validated tool used to assess athletes' physical and psychological condition daily and to provide actionable feedback regarding training processes. Each item is rated on a five-point Likert scale, where one indicates a poor (insufficient) wellness state and 5 indicates an excellent wellness state (Hooper & Mackinnon, 1995). This scale is widely utilized during training periods to monitor key factors such as physical fatigue, sleep quality, muscle soreness, and general mood in athletes, to support sustainable athletic performance.

In this study, the questionnaire consisted of six items, each rated from 1 to 5, yielding a total wellness score ranging from 6 to 30. The total score was calculated by summing the responses to the six items, with higher scores indicating better-perceived wellness status. Therefore, a score approaching 30 reflects an optimal state of wellness, whereas lower scores may indicate increased fatigue, poor recovery, or potential maladaptation. This approach has been previously recommended for monitoring athletes' readiness and recovery status (Foster et al., 2017; McGahan et al., 2018). The routine use of such feedback instruments provides valuable insights into how variations in training load affect wellness measures, supporting individualized training adjustments to enhance performance and prevent overtraining.

Warm-up Protocols

We applied the warm-up protocol in 4 different ways. The same field, training time, and similar weather conditions were considered while implementing the protocols. All protocols took 30 minutes to execute.

Protocol 1

Activation Warm-Up

In the first protocol, participants completed a 15-minute activation session indoors. Participants used foam rollers to target the hamstring, gastrocnemius, quadriceps femoris, pubis, and gluteus maximus muscles on both legs. Following this, resistance band exercises were performed for 3 minutes using THERABAND™ green elastic bands, including 15 repetitions each of ankle dorsiflexion, plantar flexion, eversion, and inversion, as well as standing glute kicks, 10 lateral steps to the right and left, and 20 banded steps forward and backwards. Stability ball exercises were completed in the same session, with 15 repetitions each of hamstring roll-ins, back extensions, and abdominal crunches, all performed over 3 minutes. The protocol also included balance exercises on a BOSU ball for 2 minutes, which involved single-leg balancing (15 seconds per leg), skipping, and lateral skipping. Finally, participants completed a 2-minute mobility exercise session using four hurdles (70 cm in height), including forward and backwards walks, rotational movements, and lateral skips in both directions.

Football-Specific Warm-Up

In the second part of the protocol, immediately following the activation exercises, participants engaged in a 15-minute warm-up session specific to football on the field. The session commenced with a 3-minute passing drill designed to enhance each participant's passing accuracy and control skills. Following this, a 5v5 possession game was conducted in a 20m x 25m area, comprised of two sets, each lasting 2 minutes, with a 1-minute rest interval between the sets. The subsequent phase involved a 2-minute drill focused on crossing and shooting, aimed at developing precise crossing and finishing techniques. This was followed by an additional 2-minute shooting drill intended to improve the participants' shooting precision and power. The session concluded with four repetitions of 8-meter sprints performed at maximum intensity.

Protocol 2

Dynamic Warm-Up

The second protocol began with a 3-minute session, during which participants, grouped in pairs, engaged in light ball drills to familiarise themselves with the field and make ball contact. This was followed by a 7-minute dynamic warm-up performed in a 10-meter area, incorporating skipping drills to activate muscles and enhance mobility. The drills included light skipping with rhythmic arm swings, high knee pulls, light butt kicks, walking lunges, straight leg kicks, high glute pulls, A-skips, B-skips, rapid high knees, carioca steps, and power skips. Each drill focused on preparing specific muscle groups and improving neuromuscular coordination. Subsequently, four repetitions of 30-meter acceleration drills were performed to simulate match-specific intensity.

Football-Specific Warm-Up

The football-specific warm-up session, as described in Protocol 1, was also implemented in Protocol 2, following the same structure and exercises.

Protocol 3

Activation Warm-Up

The activation warm-up in Protocol 3 is similar in structure and content to the activation warm-up in Protocol 1. However, to standardize the total warm-up duration to 30 minutes, the activation phase in Protocol 3 was adjusted to a total duration of 12 minutes. The primary distinction from Protocol 1 is the absence of stability ball exercises in Protocol 3, while all other components of the activation routine were maintained. This adjustment aimed to align the protocol with the study's time constraints while ensuring comparable neuromuscular activation.

Football-Specific Warm-Up

Following the completion of activation exercises, a 12-minute football-specific warm-up program was conducted on the field. This program included a 3-minute passing drill, a 5-minute 5v5 possession game in a 20m x 25m area (consisting of two 2-minute sets with a 1-minute rest between sets), a 2-minute crossing and shooting drill, and a 2-minute shooting exercise. This segment aimed to enhance the players' technical and tactical skills prior to the match.

Resistance Band and Sprint Drills

In the final 6 minutes, resistance and sprint drills were conducted, including two repetitions of a 15-meter deceleration exercise with resistance bands, two repetitions of a 15-meter acceleration exercise, five repetitions of jumping drills using resistance bands, and four repetitions of 8-meter sprints performed at maximum intensity.

Protocol 4

Dynamic Warm-Up

The dynamic warm-up segment in Protocol 4 was implemented identically to the dynamic warm-up segment in Protocol 2. The exercises, structure, and duration were consistent across both protocols to ensure standardization and comparability in dynamic warm-up practices. This alignment allowed for a reliable assessment of the subsequent components unique to each protocol.

Football-Specific Warm-Up

The football-specific warm-up segment in Protocol 4 was conducted identically to the Football-Specific Warm-Up section of Protocol 3. The structure and exercises remained consistent, ensuring standardization across protocols and enabling reliable comparisons.

Resistance Band and Sprint Drills

The resistance band segment in Protocol 4 was implemented identically to the corresponding section in Protocol 3. The structure, exercises, and duration were consistent across both protocols, ensuring standardization and enabling reliable comparisons of the effects of resistance band exercises.

Data Analysis

In this study, four distinct pre-exercise warm-up protocols (Protocol 1, Protocol 2, Protocol 3, and Protocol 4) were defined as the independent variables. The dependent variables consisted of performance measures, including 10-meter sprint time, 30-meter sprint time, and distance covered in the Yo-Yo Intermittent Recovery Test Level 2 (Yo-Yo IR2).

To assess the assumption of normality, the Shapiro-Wilk test was applied. For variables that met the assumption of normal distribution, a one-way repeated measures analysis of variance (ANOVA) was conducted. In cases where statistically significant differences were detected, post hoc comparisons were performed using Bonferroni-adjusted paired t-tests. For variables that violated the normality assumption, non-parametric alternatives—specifically, the Wilcoxon signed-rank test and the Kruskal-Wallis test—were employed. The threshold for statistical significance was set at $p < 0.05$ for all analyses.

The experimental design followed a randomized crossover structure, aiming to systematically and reliably evaluate the effects of the warm-up protocols on athletic performance and physiological outcomes. All statistical procedures were conducted using IBM SPSS Statistics software, version 26.0.

Results

Table 1. Descriptive Characteristics of Participants (N=20)

Variable	Mean ($\pm$ SD)
Age (years)	16.25 $\pm$ 0.43
Height (cm)	175.1 $\pm$ 4.69
Weight (kg)	64.45 $\pm$ 6.14
BMI	20.99 $\pm$ 1.53
Body Fat Percentage (%)	7.51 $\pm$ 2.35

As illustrated in Table 2, results of repeated measures of ANOVA revealed that performance in yoyo tests following P1, P2, P3, and P4 warmup protocols did not differ significantly. However, performance in 10 m tests following P1, P2, P3, and P4 warmup protocols differed significantly. Similarly, performance in 30 m tests also differed significantly following P1, P2, P3, and P4 warmup protocols.

Table 2. Comparison of Performance Metrics Across Four Warm-Up Protocols Using Repeated Measures ANOVA

	P1± SD	P2± SD	P3± SD	P4± SD	F	p	η ²
Yo-Yo (m)	556.00±137.12	548.00±124.71	545.00±126.97	560.00±136.73	.104	.957	.005
10 m (s)	1.59±0.06	1.63±0.06	1.69±0.07	1.67±0.06	18.128	.000*	.448
30 m (s)	4.04±0.12	4.03±0.12	4.20±0.15	4.16±0.14	36.871	.000*	.660

*P<.05

*: statistically significant

η²: indicates the effect size or magnitude of the relationship between variables

The findings presented in the table demonstrate the effects of the warm-up protocols on different components of physical capacity. The Yo-Yo Intermittent Recovery Test results ($F(3, 57) = 0.104$, $p = .957$, $\eta^2 = 0.005$) did not differ significantly between protocols, indicating that endurance performance remained similar regardless of the warm-up model used.

In contrast, the effect size for the 10 m sprint time ($\eta^2 = .448$) and its high statistical significance ($F(3, 57) = 18.128$, $p < .001$) underscore the sensitivity of short-distance acceleration ability to the content of the warm-up. For the 30 m sprint, the effect size increased further ($\eta^2 = .660$; $F(3, 57) = 36.871$, $p < .001$), indicating that the choice of protocol has a significant influence on maximal sprint performance (Table 2).

Table 3. 10 m Sprint Test: Pairwise Comparisons of Warm-Up Protocols with Bonferroni Adjustment

Comparison	Mean Difference (s)	Standard Error (s)	p-value
P1 – P2	0.04	0.02	.08
P1 – P3	0.1	0.02	.000*
P1 – P4	0.08	0.01	.000*
P2 – P3	0.06	0.01	.001*
P2 – P4	0.04	0.02	0.15
P3 – P4	0.02	0.02	1

*P<.05

*: statistically significant

Table 3 summarizes the Bonferroni-corrected pairwise contrasts for 10 m sprint performance following each warm-up protocol. Protocols P1 and P2—both traditional dynamic routines—elicited significantly faster sprint times compared with resistance-band protocols P3 and P4. Specifically, P1 outperformed P3 by a mean difference of 0.10 s ($p < .001$) and P4 by 0.08 s ($p < .001$), while P2 was 0.06 s faster than P3 ($p = .001$). Neither the P1–P2 comparison (mean difference = 0.04 s, $p = .08$) nor the P2–P4 comparison (mean difference = 0.04 s, $p = .15$) reached statistical significance, and no difference emerged between P3 and P4 (mean difference = 0.02 s, $p = 1.00$). These findings indicate that the incorporation of resistance bands attenuates short-distance acceleration, whereas dynamic warm-ups without added resistance confer superior 10 m sprint performance.

Table 4. 10 m Sprint Test: Pairwise Comparisons of Warm-Up Protocols with Bonferroni Adjustment

Comparison	Mean Difference (s)	Standard Error (s)	p-value
P1 – P2	0.01	0.02	1
P1 – P3	0.16	0.02	.000*
P1 – P4	0.11	0.01	.000*
P2 – P3	0.17	0.02	.000*
P2 – P4	0.12	0.02	.000*
P3 – P4	0.05	0.02	0.17

*P<.05

*: statistically significant

Table 4 presents Bonferroni-adjusted pairwise contrasts for 10-meter sprint times across the four warm-up protocols. No significant difference was observed between P1 and P2 (mean difference = 0.01 s, $p = 1.00$), nor between P3 and P4 (mean difference = 0.05 s, $p = 0.17$). In contrast, both traditional dynamic protocols (P1, P2) produced significantly faster sprints than the resistance-band protocols: P1 vs. P3 (mean difference = 0.16 s, $p < .001$), P1 vs. P4 (mean difference = 0.11 s, $p < .001$), P2 vs. P3 (mean difference = 0.17 s, $p < .001$) and P2 vs. P4 (mean difference = 0.12 s, $p < .001$). These results reinforce that added resistance impairs short-distance acceleration relative to purely dynamic warm-ups.

Table 5. Pre-Warm-Up Wellness Scores and ANOVA Results

Measurements	Mean $\pm$ Standard Deviation	Standard Error	F	η^2	p-value
p1 wellness	21,80 $\pm$ 1,361	0,304	1.165	.058	.331
p2 wellness	21,65 $\pm$ 2,084	0,466			
p3 wellness	21,45 $\pm$ 2,164	0,484			
p4 wellness	21,00 $\pm$ 2,128	0,476			

*P <.05: statistically significant

Athletes' perceived wellness before each warm-up protocol (P1–P4) is summarized as mean $\pm$ SD and standard error (SE) in Table X. Baseline wellness did not differ significantly across conditions (P1: 21.80 $\pm$ 1.36, SE = 0.30; P2: 21.65 $\pm$ 2.08, SE = 0.47; P3: 21.45 $\pm$ 2.16, SE = 0.48; P4: 21.00 $\pm$ 2.13, SE = 0.48). A one-way repeated-measures ANOVA confirmed no main effect of protocol on wellness ($F(3,57) = 1.165$, $p = 0.331$, $\eta^2 = 0.058$), indicating homogeneous pre-intervention perceptual states among participants. The small partial eta-squared further substantiates the equivalence of baseline readiness across all warm-up approaches (Table 5).

	1	2	3	4	5
Mood State	Highly annoyed/irritable/down	Snappiness at teammates, family and co-workers	Less interested in others/activities than usual	Good mood	Very positive mood
Sleep Quality	Hardly slept at all	Tossed and turned	Reasonable/Just OK	Good night's sleep; Feeling refreshed	Had a great sleep. Feeling very refreshed
Energy Levels	Very lethargic – no energy at all	Very low energy levels	Reasonable energy levels	Good energy levels	Full of energy
Muscle Soreness	Extremely sore	Very sore	Quite sore	Mild soreness	Not sore at all
Diet yesterday	All meals high sugar/processed food, no fruit/veg	Some meals high sugar/processed food, no fruit & veg	Ate reasonably, some sugar/processed food intake, at least 1 serving of veg	Ate well, low sugar/processed food intake, 2 or more servings veg & fruit	Ate really well, no added sugar/processed foods and lots of veg and some fruit
Stress	Highly stressed	Feeling stressed	Reasonable / Just OK	Relaxed	Very relaxed

Figure 1. Daily wellness questionnaire, each question scored on a five-point scale with 1 and 5 representing poor and very good wellness ratings (based on McGahan et al., 2020).

Discussions

The findings from the sprint tests demonstrate the impact of different warm-up protocols on speed performance. In the 10-meter sprint test, players who performed the P1 protocol recorded the fastest times, whereas the P3 protocol resulted in the lowest acceleration rates. In the 30-meter sprint test, the best performance was achieved by players following the P2 protocol, while warm-up protocols involving resistance bands (P3 and P4) significantly reduced sprint performance. These findings indicate that excessive resistance loading may have detrimental effects on sprint performance.

The literature suggests that high-resistance warm-up protocols increase muscle fatigue, leading to a short-term reduction in anaerobic power output (Bishop, 2003; Faigenbaum et al., 2006). While resistance exercises can activate the post-activation performance enhancement (PAPE) mechanism, it is proposed that excessive loading may suppress this effect (Rhea et al., 2009; Tillin & Bishop, 2009). Similarly, Rhea et al. (2009) reported that high-resistance warm-up protocols might disrupt the stretch-shortening cycle (SSC) of the muscles, negatively affecting sprint performance. McBride et al. (2005) and Faigenbaum et al. (2006) also indicated that high-resistance exercises increase muscle fatigue, which can impair explosive power production in the short term. These findings explain the increase in sprint time observed in the P4 protocol. Although warm-ups with high-resistance elastic bands may enhance neuromuscular activation, the accompanying fatigue can negatively influence sprint performance.

Moreover, the literature widely supports that dynamic and sport-specific warm-up routines enhance neuromuscular activation and consequently improve sprint performance (Gelen, 2008; Bishop, 2003). However, although warm-ups involving high-resistance loading may theoretically facilitate short-distance acceleration via the post-activation performance enhancement (PAPE) mechanism, they can have detrimental effects on sprint performance due to induced fatigue (Kilduff et al., 2011; Turner et al., 2015). Consistent with these findings, the present study observed that the P3 and P4 protocols did not yield the expected improvements in sprint performance; instead, they resulted in performance decrements, likely attributed to excessive fatigue. These

results suggest that the effects of resistance-based warm-up protocols are dose-dependent, and excessive loading may impair performance in neuromuscularly demanding tasks such as sprinting. Kyranoudis et al. (2018) reported that 20-meter sprint performance improved only after a football-specific dynamic warm-up, whereas protocols involving excessive resistance or non-specific stimuli did not produce significant benefits.

In conclusion, the findings of this study provide valuable insights into the effects of warm-up protocols on sprint performance in soccer players. In both the 10- and 30-meter sprint tests, modern (P1) and traditional dynamic warm-up protocols (P2), which induced less fatigue, were found to be more effective, while high-resistance warm-up protocols negatively affected sprint performance. Therefore, warm-up protocols should be designed to optimize neuromuscular activation while avoiding excessive fatigue. Previous research has emphasized that high-resistance warm-up protocols may compromise short-term explosive performance as a result of fatigue-induced limitations, while dynamic and sport-specific protocols tend to facilitate greater improvements in sprint performance (Kyranoudis et al., 2021). In particular, balancing post-activation performance enhancement (PAPE) and fatigue appears to be a critical factor for optimizing sprint performance (Bishop, 2003; Kilduff et al., 2011; Turner et al., 2015). Accordingly, coaches and strength and conditioning specialists should tailor warm-up protocols based on the sport, the athlete's training history, and the targeted sprint performance. The data obtained from the Yo-Yo IR2 test indicated that there were no statistically significant differences in aerobic performance levels between the different warm-up protocols. This finding suggests that warm-up exercises have no acute effect on aerobic capacity and that the development of this physiological parameter is primarily dependent on long-term training adaptations. Our findings align with the view of Bangsbo (1994), who stated that improvements in endurance are associated with continuous and systematic training practices. Similarly, Buchheit and Laursen (2013) emphasized that increases in aerobic capacity require long-term physiological adaptations and cannot be achieved through short-term interventions.

The football players who participated in our study exhibited similar aerobic performance levels following the implementation of all warm-up protocols. Karaday and Köklü (2018) also reported that warm-up exercises do not significantly improve endurance in the short term, thus supporting our findings. The literature widely agrees that aerobic endurance is primarily developed through long-term, planned, and systematic training (Helgerud et al., 2001; Iaia et al., 2009). On the other hand, Bishop (2003) noted that while warm-up increases muscle temperature, enhances the rate of metabolic reactions, and improves nerve conduction velocity, these effects are mainly related to neuromuscular preparation and are insufficient to directly influence aerobic capacity, which depends on the oxygen transport capacity of the cardiorespiratory system. Similarly, Smith et al. (2020) stated that warm-up can improve acute physiological readiness but does not contribute to long-term aerobic adaptation. The results of our study are consistent with the existing literature. Bangsbo (1994) and Karaday & Köklü (2018) concluded that different warm-up methods do not lead to significant improvements in aerobic capacity. Buchheit and Laursen (2013) highlighted that high-intensity interval training (HIIT) is an effective method for increasing $\text{VO}_{2\text{max}}$ levels, but such adaptations require structured, sufficient duration, and goal-oriented training loads. Our findings indicate that aerobic capacity cannot be developed through acute warm-up interventions and instead requires a long-term and organized training plan.

Some studies have suggested that warm-up may improve oxygen transport and consumption by increasing body temperature, thereby offering advantages in short-duration performance tests. For example, Smith et al. (2020) noted that this physiological response could enhance performance in short-term tests. Similarly, Lopez et al. (2017) reported that warm-up protocols involving dynamic stretching and high-intensity exercises could improve running economy, allowing athletes to consume less oxygen at given speeds and maintain performance for longer durations. Nevertheless, in our study, all protocols elicited similar physiological responses, and no statistically significant differences were found between the warm-up protocols in the Yo-Yo IR2 test. This suggests that the acute effect of warm-up on aerobic performance is limited.

Overall, our study demonstrates that the development of aerobic capacity is only possible through long-term, systematic, and appropriately structured training. Midgley et al. (2007) stated that short-term physiological effects are insufficient to create meaningful adaptations in the aerobic system. Similarly, Taylor et al. (2012) reported that different warm-up protocols do not lead to significant changes in aerobic performance. Based on these findings, we conclude that the warm-up protocols applied in our study did not have a significant effect on the aerobic capacity of the football players.

Conclusions

This study investigated the acute effects of four different warm-up protocols on sprint and endurance performance in elite youth football players. The findings revealed no statistically significant differences in endurance capacity as measured by the Yo-Yo Intermittent Recovery Test Level 2. However, notable differences in sprint performance were observed depending on the type of warm-up protocol applied.

The results underscore the importance of carefully structuring warm-up routines, particularly in activities that demand high-intensity efforts such as sprinting. Warm-up strategies that optimize neuromuscular activation while minimizing fatigue were found to be more effective. In contrast, protocols involving excessive resistance or overly complex movements may impair sprint performance due to premature fatigue and reduced

efficiency of the neuromuscular system. From a practical standpoint, these findings offer valuable guidance for coaches, strength and conditioning specialists, and sport scientists when designing pre-competition warm-up routines. The content, duration, and intensity of the warm-up should be adapted to match the physical demands of the match and the individual characteristics of the athlete. Resistance-based warm-ups may have a role during training periods for strength development, but their use before matches requiring maximal sprint performance should be reconsidered. Dynamic and sport-specific warm-up protocols based on progressive loading appear to facilitate better performance outcomes without inducing fatigue.

From a theoretical perspective, the study contributes to the literature by highlighting the dose-response relationship between acute preparatory strategies and performance outputs in intermittent team sports. Moreover, the findings reinforce the understanding that improvements in aerobic capacity result from long-term, systematic training rather than acute interventions. Future research should explore the efficacy of these protocols across different age groups, sports disciplines, and phases of the competitive season to enhance the generalizability of the findings. Longitudinal studies examining the chronic effects of various warm-up strategies on performance development, injury prevention, and readiness could provide further insights into designing individualized, evidence-based warm-up models.

Practical implications

The findings of this study provide valuable insights for coaches, sports scientists, and athletes in designing effective pre-match warm-up routines. Warm-up protocols should be tailored to the specific requirements of the sport and the individual needs of the athletes. For activities requiring explosive power and speed, such as sprinting, dynamic warm-up exercises incorporating equipment like foam rollers, gym balls, and BOSU balls are recommended to enhance performance while minimizing muscle fatigue. Although resistance bands are effective for strength development, their use in pre-match warm-up routines should be carefully monitored. Excessive or high-intensity resistance exercises may lead to muscle fatigue and reduced sprint performance, particularly in scenarios where maximum effort is required.

Incorporating exercises that target neuromuscular activation, such as dynamic stretching and sport-specific drills, can enhance the efficiency of the Stretch-Shortening Cycle (SSC), contributing to improvements in speed and agility. Moreover, avoiding excessive loading in warm-up routines, especially those involving resistance exercises, is crucial to prevent potential adverse effects on performance. These recommendations are particularly relevant for youth athletes, emphasizing the importance of adopting progressive and scientifically grounded approaches to preparation.

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