

A short-term weighted-vest anaerobic training model to enhance anaerobic endurance in soccer players

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Abstract

Introduction. Soccer requires a combination of high-intensity physical, technical, and tactical skills, with a particular emphasis on anaerobic endurance. **Aim of Study.** This study aims to develop and test the effectiveness of the weighted-vest-based (WV) anaerobic soccer training (AnST) model as an integrated approach to improving players' anaerobic endurance without increasing training volume. **Material and Methods.** This study involved 33 male amateur soccer players randomly assigned to three groups: Group A with a WV of $12.40 \pm 0.13\%$ body mass, Group B with $7.88 \pm 0.08\%$, and Group C without additional load. Participants had an average weight of 61.75 ± 6.22 kg, height of 164.88 ± 5.39 cm, age of 19.94 ± 1.03 years, and BMI of 22.73 ± 2.24 kg/m². Anaerobic endurance was assessed using the running-based anaerobic sprint test (RAST) for peak power (PP), average power (AP), and fatigue index (FI). ANCOVA with pretest covariates was used for PP and FI, and Quade's nonparametric ANCOVA for AP due to non-homogeneous slopes. Post hoc comparisons employed Tukey's tests (PP, FI), and pairwise Quade tests (AP), with Cohen's *d* effect sizes. **Results.** ANCOVA results showed significant differences between groups for PP ($p = 0.006$) and FI ($p = 0.033$), with pretest scores also significantly influencing the outcomes ($p < 0.001$). Post hoc tests indicated that Group A had significantly higher PP ($p = 0.004$) and lower FI ($p = 0.020$) compared to Group C. For AP, Quade-adjusted ranks showed Group A was significantly higher than Group C ($p = 0.007$). Effect sizes were large (Cohen's *d* = 1.53, 1.24, and 1.05), highlighting the substantial impact of WV training on anaerobic performance. **Conclusions.** A WV corresponding to $12.40 \pm 0.13\%$ of body mass produced the greatest improvement in soccer players' anaerobic endurance compared with lighter or no load.

KEYWORDS: soccer performance, anaerobic endurance, weighted-vest training.

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Introduction

Soccer demands high levels of physical ability, particularly speed and anaerobic endurance. Players must be able to perform repeated sprints - approximately 31 to 33 per match [1] - at various high-intensity speeds, ranging from >19.7 km/h for 645.7 meters, $19.8\text{--}25.2$ km/h for 771.0 meters, $21.1\text{--}24.0$ km/h for 518.2 meters, and $19.8\text{--}25.1$ km/h for 617.7 meters [2]. In addition, understanding tactics in attacking and defending transitions is essential because the tactical aspects of sprinting play a role in designing specific exercises [3]. To maintain performance throughout the game, players must have optimal anaerobic endurance, particularly within the anaerobic lactate energy system [4]. A study shows that soccer involves a combination of high-intensity activities superimposed on periods of lower-intensity efforts, requiring a well-developed

capacity in both the aerobic and anaerobic energy systems [5]. Referring to soccer's high physical and tactical demands, training programs must be designed at high intensity to meet the needs of the game. In previous studies, researchers have developed an integrated training model that combines technical, physical, and tactical aspects in an anaerobic soccer training (AnST) approach. This model has been proven effective in improving players' physical performance, particularly their aerobic and anaerobic endurance [6]. This study aims to develop a more intensive AnST model by integrating a weighted vest (WV) to optimize improvements in anaerobic endurance, as reflected in changes in peak power (PP), average power (AP), and fatigue index (FI) in soccer players.

For elite athletes seeking to improve speed and muscle strength, strength training (ST), such as plyometrics, weight lifting, and resistance sled training, is commonly used [7]. These components support explosiveness and speed, which are crucial in soccer. However, ST is often performed separately from the main training on the field [8]. In contrast, game-based approaches are more popular because they resemble the demands of a match and improve aerobic and anaerobic endurance [9]. Although this method effectively develops players' physical capacity, it places less emphasis on strength components, even though muscle strength is essential for supporting optimal performance. The imbalance between game-based training and ST indicates the need for an integrated approach to combine both aspects without excessively increasing training volume. Weight training and AnST are performed in separate sessions, potentially increasing the risk of fatigue accumulation due to high training loads. These external loads are expected to improve anaerobic endurance while maintaining tactical and technical aspects.

High-intensity training can be modified through resistance training or the use of WV [10]. Its use has been shown to improve sprint acceleration, the ability to perform repeated sprints, jump height, agility in changing direction, and the effectiveness of kicks in soccer players [11]. Training with WV forces athletes to work harder due to the additional load, which aims to increase anaerobic and muscle endurance. Most studies still examine this method separately without integrating endurance and strength into one efficient program, even though the concept of concurrent training already combines aerobic endurance and strength [12]. However, this study offers something new by simultaneously integrating AnST and ST (weighted vest). This approach has rarely been studied in soccer,

but it has the potential to increase anaerobic endurance without adding to the training volume. In addition, this study also provides an understanding of the extent to which WV can be optimized in soccer training, resulting in a more efficient solution for coaches in developing programs that meet the physical and tactical demands of the game.

Aim of Study

This study aimed to develop and evaluate the effectiveness of a novel integrated, weighted-vest-based AnST model designed to enhance anaerobic endurance in amateur soccer players. Specifically, the study sought to determine the optimal WV load that maximizes improvements in anaerobic performance indicators, such as PP, AP, and FI, without increasing total training volume.

Material and Methods

Study participants

This study involved 33 male amateur soccer players who were randomly divided into three groups using a randomized parallel matched-group design. Each group consisted of 11 participants: Group A with a WV load of $12.40 \pm 0.13\%$ of body mass ($n = 11$), Group B with a WV load of $7.88 \pm 0.08\%$ of body mass ($n = 11$), and Group C without additional load ($n = 11$). These loads were selected based on previous research recommending $\leq 20\%$ of body mass for resisted sprinting to optimize performance adaptations without excessively altering sprint mechanics [13]. The variability in the percentage of body mass is attributable to the technical specification of the WV, which is available only in 200-gram load increments. As a result, the load could not be adjusted with absolute precision for each player's body mass, requiring rounding to the nearest available plate unit and resulting in small deviations from the target percentage. An a priori power analysis was conducted using G*Power 3.1. Based on an expected medium effect size ($f = 0.25$), $\alpha = 0.05$, and power = 0.80, the required sample size was estimated to be 33 participants for three groups (11 per group). The current study included exactly 33 participants, which meets the estimated requirement. However, the relatively small group size should be considered when interpreting the results.

Participant eligibility criteria included: (i) no injuries, illnesses, or physical limitations during the study period; (ii) completion of at least 90% of the total scheduled training sessions; and (iii) participation in the entire

series of tests, both at the pretest and posttest stages. All participants received a detailed explanation of the study's objectives, procedures, benefits, and potential risks and signed an informed consent form before the study began. This study was conducted in accordance with the Declaration of Helsinki. The research protocol was approved by the Health Research Ethics Committee of the Health Research Ethics Committee of Nahdlatul Ulama University of Surabaya (Project ID: 0449/EC/KEPK/UNUSA/2024, Date of approval: 28 November 2024).

Study organization

This study employed an experimental method with a randomized parallel matched group design to examine the effect of WV-based AnST on soccer players' anaerobic performance. Participants were randomly allocated into three groups using a computer-based randomization sequence, and allocation was concealed using sealed opaque envelopes to prevent selection bias. Matching was performed based on pre-intervention RAST anaerobic endurance scores to minimize initial performance differences between groups. The intervention lasted three weeks, consisting of four training sessions per week (Monday morning, Wednesday morning, Friday morning, and Saturday afternoon). During the intervention period, participants did not engage in any additional training or team matches, ensuring that all focus was on the research program and external variables were controlled. The three-week intervention period was chosen to represent a short-term training cycle commonly implemented in soccer conditioning programs. Previous research has demonstrated that significant anaerobic performance adaptations can occur within 2 to 4 weeks of high-intensity or resisted sprint training. Such short-term (2–4 week) training cycles are widely adopted in soccer, particularly during pre-season, in-season microcycles, and return-to-play phases. This approach is based on two main considerations: (i) the practical need to achieve rapid and meaningful improvements in sprint performance, repeated-sprint ability, and agility, and (ii) growing evidence that substantial anaerobic adaptations can be attained within a relatively short period when training is well-structured and individualized [14]. Each session lasted approximately 60 to 75 minutes and included a standardized structure of warm-up, main training (core anaerobic drills), and cool-down phases. The main difference between groups was the external load applied through the WV. The WV-based AnST program integrated sprint intervals, shuttle runs, and

anaerobic small-sided game (SSG) formats to target repeated high-intensity efforts characteristic of soccer.

All training sessions were directly supervised by a certified strength and conditioning coach to ensure protocol consistency, safety, and adherence to the intended intensity level, while external confounding variables such as training frequency, recovery duration, and environmental conditions were controlled across groups. Outcome assessors were blinded to group allocation (single-blind design) to minimize measurement bias during pre- and post-intervention testing. However, internal load indicators, such as heart rate (HR) and session rating of perceived exertion (RPE), were not measured, limiting the ability to confirm whether training intensity was fully comparable between groups.

Measurements

Anaerobic endurance in this study was evaluated using the RAST test at the pretest and posttest stages. This test was designed to measure soccer players' anaerobic endurance through three leading indicators, namely PP, AP, and FI. The RAST procedure consisted of six 35-meter sprints with a 10-second rest interval between each sprint. The test was conducted on a flat, hard surface using a photocell timer to record each sprint's start and finish times. Each participant started running at the sound of a beep and ran as fast as possible to the finish line. After all sprints were completed, the travel time was used to calculate maximum power, minimum power, AP, and the FI using the formula: $\text{Power} = (\text{body mass} \times \text{distance}^2) \div \text{time}^3$ [15].

Training program

The ANST with WV training protocol was designed to combine repeated sprints with possession-based SSG to stimulate high-intensity transition actions that frequently occur in competitive soccer. The program was specifically structured to elicit anaerobic metabolic demand while maintaining equivalent training volume across groups, with the WV serving as the only external load differentiator between interventions.

Based on Figure 1, the field is divided into three main areas: Area A (SSG 4v2), Area B (a 20-meter sprint zone), and Area C (SSG 4v2). Players are divided into three teams: red, blue, and black, each consisting of six players. Each SSG area has two players from each team (two red, two blue, two black), so the game format is four against two, with four players in possession and two acting as defenders. Each set begins with the black team defending for 30 seconds in both SSG areas. The red and blue teams maintain possession, while the black

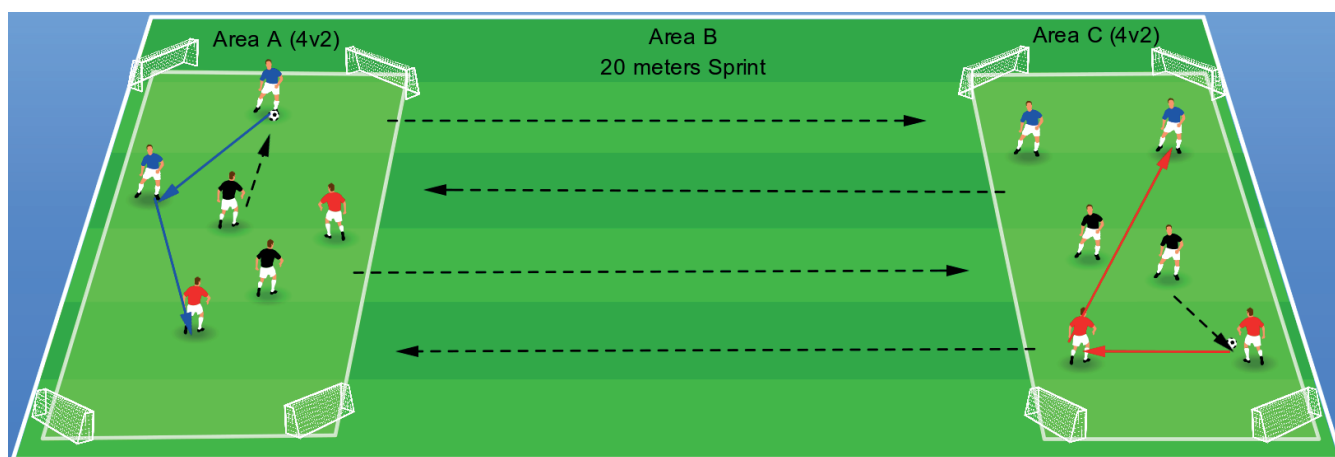


Figure 1. Training Area

players attempt to steal the ball and score goals into four small goals placed on the sides of the field. After 30 seconds, two black players from Area A sprint 20 meters across Area B to Area C, while two black players from Area C simultaneously run towards Area A. Upon arrival at their destination, they immediately continue the next 30-second SSG session. This sequence SSG, sprint, SSG, sprint is repeated until the black players complete four sprints (4×20 meters) and four SSGs (two in Area A and two in Area C) in one complete set. The work-to-rest ratio follows a 1:2 pattern, where two phases of SSG are used as active recovery between high-intensity sprints. After completing one set, the teams switch roles: the red team acts as the defender, replacing the black team, followed by the blue team. Each training session consists of 8 sets, with direct supervision by a certified coach to ensure maximum sprint intensity and consistency in the duration of each training phase. Based on this design, each player performs 32 sprints per session ($4 \text{ sprints} \times 8 \text{ sets}$) with a total distance of 640 meters of high-intensity sprinting per session. This activity pattern produces a high and repetitive high-speed running stimulus, reflecting the anaerobic demands of actual game situations.

Statistical analysis

All data were analyzed using Jamovi statistical software. Data normality was tested using the Shapiro–Wilk test, while variance homogeneity was tested using Levene’s test. Homogeneity of regression slopes was tested to ensure that the relationship between pretest and posttest scores was consistent across groups, which is an essential assumption for ANCOVA. ANCOVA was used to test the hypothesis with pretest scores

as covariates to control for initial variation between groups before the treatment was administered. This approach allowed the effect of the treatment on posttest scores to be analyzed more accurately because the influence of participants’ initial abilities was taken into account. It enabled the researchers to determine whether differences in posttest results among Groups A, B, and C were truly caused by the treatment, after considering the significant influence of the initial (pretest) values. If the assumption of homogeneous slopes was violated, Quade’s nonparametric ANCOVA was applied to analyze variables with unequal slopes. Furthermore, post hoc tests were conducted using Tukey’s test for ANCOVA and pairwise comparisons of adjusted ranks for Quade’s test to identify which groups showed statistically significant differences. Additionally, effect sizes were calculated using Cohen’s d to determine the magnitude of the treatment effect for each variable, with the following interpretations: small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$).

Results

Table 1 presents descriptive characteristics of the participants in each group. The three groups were similar in terms of age ($\text{mean } 19.94 \pm 1.03$ years), playing experience (5.82 ± 0.64 years), and height (164.88 ± 5.39 cm). Minor differences were observed in body mass and body mass index, but these remained within a comparable range. Overall exercise adherence was high across all groups (mean 96.21%), indicating consistent participation in the training program.

The descriptive data in Table 2 above indicate that, following the treatment, Group A showed the greatest increase in PP (from 471 ± 71.2 to 527 ± 78.4 watts)

Table 1. Sample characteristics

Variable	Group A	Group B	Group C	Total
Subjects (n)	11	11	11	33
Age (years)	20.09 ± 1.05	19.91 ± 1.20	19.82 ± 0.99	19.94 ± 1.03
Soccer experience (years)	5.82 ± 0.63	5.91 ± 0.74	5.73 ± 0.67	5.82 ± 0.64
Height (cm)	163.68 ± 3.99	164.95 ± 4.90	166.02 ± 6.83	164.88 ± 5.39
Body mass (kg)	58.23 ± 5.36	64.13 ± 5.35	62.88 ± 5.78	61.75 ± 6.22
BMI (kg/m ²)	21.27 ± 1.73	23.56 ± 1.71	22.92 ± 2.80	22.73 ± 2.24
Adherence (%)	96.97	96.21	95.45	96.21

Note: Data are presented as mean and standard deviation (SD)

compared with Groups B and C. A similar pattern was also observed for AP, with Group A increasing from 381 ± 52.4 to 421 ± 46.8 W, while Groups B and C showed smaller improvements. For FI, all three groups experienced a decrease after the intervention, but Group A showed the most significant decrease (from $38.8 \pm$

6.15 to 33.6 ± 7.01), indicating an increase in anaerobic endurance efficiency.

The normality of the data was assessed using the Shapiro-Wilk test, and all variables, including PP, AP, and FI, were found to be normally distributed ($p > 0.05$). Homogeneity of variance was tested using

Table 2. Data description

	Variable	Group	N	Mean	Median	SD	Minimum	Maximum
PP	Final score	Group A	11	527	509	78.4	445	672
		Group B	11	557	545	82.2	462	695
		Group C	11	520	536	54.1	428	584
	Pretest score	Group A	11	471	452	71.2	402	613
		Group B	11	523	502	71.4	435	670
		Group C	11	512	530	63.0	386	591
AP	Final score	Group A	11	421	434	46.8	364	503
		Group B	11	440	404	72.2	367	577
		Group C	11	408	393	57.4	332	486
	Pretest score	Group A	11	381	368	52.4	319	485
		Group B	11	411	393	49.2	352	494
		Group C	11	403	392	55.2	322	481
FI	Final score	Group A	11	33.6	35.3	7.01	19.2	43.6
		Group B	11	35.4	33.3	6.22	26.3	47.5
		Group C	11	37.6	39.8	12.69	19.3	57.6
	Pretest score	Group A	11	38.8	40.1	6.15	27.5	48.4
		Group B	11	38.4	36.9	5.72	30.9	48.4
		Group C	11	37.7	35.8	8.69	26.9	52.4

Note: PP – peak power, AP – average power, FI – fatigue index

Levene's test, and no significant differences in variance were observed among groups for PP ($p = 0.205$), AP ($p = 0.863$), and FI ($p = 0.084$), indicating that this assumption for ANCOVA was satisfied. Homogeneity of regression slopes was then examined by testing the interaction between the covariate (pretest scores) and group (method). The interaction was not significant for PP ($p = 0.134$) and FI ($p = 0.258$), indicating that the effect of the pretest on the posttest did not differ significantly among groups, and standard ANCOVA was appropriate for these variables. However, for AP, the interaction was significant ($p = 0.0207$), showing that slope homogeneity was violated. Therefore, Quade's test, a nonparametric ANCOVA that accounts for covariates without requiring slope homogeneity, was applied for AP. Post hoc comparisons were conducted using adjusted ranks for Quade's test, while estimated marginal means (Adj. mean $\pm$ SE) were reported for PP and FI.

The results of the ANCOVA in Table 3 show a significant group effect on the anaerobic performance variables PP and FI, with PP ($p = 0.006$, $\eta^2_p = 0.299$) and FI ($p = 0.033$, $\eta^2_p = 0.210$). The pretest score as a covariate also had a significant effect on both variables ($p < 0.001$), indicating that the players' initial abilities contributed to the final outcomes. Based on these findings, a post hoc analysis was conducted to identify which group showed the most significant improvement in anaerobic endurance after the intervention.

Table 3. ANCOVA test

Variable	Source	Sum of squares	Df	Mean square	F	P	η^2_p
PP	Overall model	142973	3	47658	50.52	<.001	
	Group	11436	2	5718	6.18	0.006	0.299
	Pretest score	131537	1	131537	142.20	<.001	0.831
	Residuals	26826	29	925			
FI	Overall model	2094	3	698.1	36.52	<.001	
	Group	144	2	71.8	3.86	0.033	0.210
	Pretest score	1951	1	1950.6	104.97	<.001	0.784
	Residuals	539	29	18.6			

Note: PP – peak power, FI – fatigue index, Df – degrees of freedom, F – F- static, P – p -value (significance level), η^2_p = partial eta squared.

Table 4 presents the results of Quade's nonparametric ANCOVA, showing a significant effect of training methods on AP after controlling for pretest scores ($F = 4.144$, $DFH = 2$, $DFE = 30$, $p = 0.026$). This result was followed by post hoc pairwise comparisons to determine which groups differed significantly.

Table 4. Quade's nonparametric analysis of covariance

F	DFH	DFE	P
4.114	2	30	0.26

Note: F – F-statistic, DFH – degrees of freedom for hypothesis, DFH – degrees of freedom for error, P – p -value (significance level)

Table 5 above presents the post hoc pairwise comparisons between groups for anaerobic performance variables. Adjusted mean $\pm$ SE from ANCOVA was used for PP and FI, whereas adjusted rank $\pm$ SE from Quade nonparametric ANCOVA was used for AP due to non-homogeneous regression slopes. Comparisons between groups, p -values, and effect sizes (Cohen's d) are displayed. The results show that Group A (highest WV load) exhibited higher PP than Group C (mean difference = 46.6, $p = 0.004$, $d = 1.53$), higher AP based on Quade's nonparametric ANCOVA ($t = 2.872$, $df = 30$, $p = 0.007$, $d = 1.05$), and lower FI (mean difference = 36.0, $p = 0.020$, $d = 1.24$) compared with Group C, indicating significant improvements. In contrast, the moderate-load group

Table 5. Post hoc test

Variable	Group	N	Adj. mean $\pm$ SE / adj. rank $\pm$ SE	Comparison	<i>p</i> -value	Cohen's <i>d</i>
PP	A	11	527 $\pm$ 23	A vs. B	0.318	0.66
	B	11	557 $\pm$ 24	A vs. C	0.004	1.53
	C	11	520 $\pm$ 16	B vs. C	0.120	0.87
AP	A	11	421 $\pm$ 14 (adj. rank)	A vs. B	0.213	0.46
	B	11	440 $\pm$ 22 (adj. rank)	A vs. C	0.007	1.05
	C	11	408 $\pm$ 18 (adj. rank)	B vs. C	0.120	0.58
FI	A	11	33.6 $\pm$ 2.1	A vs. B	0.670	0.38
	B	11	35.4 $\pm$ 1.9	A vs. C	0.020	1.24
	C	11	37.6 $\pm$ 3.8	B vs. C	0.125	0.86

Note: PP – peak power, AP – average power, FI – fatigue index. PP and FI show adjusted mean $\pm$ SE from ANCOVA; AP shows adjusted rank $\pm$ SE from Quade's test due to non-homogeneous slopes

(Group B) generally did not differ significantly from either of the other groups.

Discussion

The results of this study indicate that the group with a WV of $12.40 \pm 0.13\%$ of body mass (Group A) had lower pretest scores than the other groups, but showed the most tremendous improvement in PP and AP and the most significant decrease in FI. Although the ANCOVA results showed that pretest scores had a strong influence on the final results ($\eta_p^2 = 0.77\text{--}0.83$), the group effect was also significant ($p < 0.05$), indicating that differences between interventions still played a role after controlling for initial conditions. Thus, WV training with higher loads proved more effective in increasing anaerobic endurance, especially in players with lower basic abilities. This improvement indicates that the training program effectively developed explosive capacity, average work capacity, and tolerance to muscle fatigue related to the anaerobic energy system. These results are not much different from previous studies after adding a special training program using WV to the main training routine of soccer players [16]. In addition, this combination of exercises falls into the category of concurrent training, an approach combining two different types of exercises in one program, generally aerobic endurance training and ST [17–19]. The integration of WV in AnST allows players to develop anaerobic endurance and muscle strength simultaneously without separating endurance and ST sessions.

The increase in PP in both groups, especially at a load of $12.40 \pm 0.13\%$ of body mass, can be explained by the overload principle, in which additional resistance

through WV forces the muscles to contract with greater power during each sprint. These encourage the recruitment of more motor units, including type II (fast-twitch) muscle fibers, which play a dominant role in high-intensity, short-duration activities [20, 21]. The load of $12.40 \pm 0.13\%$ of body mass provides a sufficiently large mechanical stimulus to trigger higher neuromuscular adaptation, resulting in a more significant increase in PP [22]. In addition, performance improvement can also be attributed to biomechanical efficiency, which arises from increased force output and neuromuscular coordination during sprints with additional load [23].

In AP, the improvement in all groups indicates an overall improvement in anaerobic endurance. Additional load during training can increase phosphagen and anaerobic glycolysis capacity, thereby improving the ability to maintain high power in several sprint repetitions. The group with a load of $12.40 \pm 0.13\%$ of body mass showed greater improvement, possibly because this load provided an optimal combination of strength and speed stimuli, making the transfer of adaptations to repeated-sprint performance more effective [24]. In addition, previous studies have also shown that using WV in training can improve acceleration, repeated sprints, and direction changes [25–27].

Meanwhile, the decrease in FI (or increase in its efficiency value) indicates that players can maintain consistent sprint performance over several repetitions, which is related to an increase in buffering capacity against the accumulation of hydrogen ions (H^+) and lactate. A recent study reported that using WV in re-

warm-up training can increase muscle buffering capacity and delay performance decline in the second half of soccer matches [10]. Although this study is slightly different, the emphasis on WV is relatively the same. A 12% load has also provided a greater metabolic stimulus for increased anaerobic enzyme activity and fast energy system adaptation [28]. In addition, it was found that WV training during SSG strengthens neuromuscular resistance to fatigue [21]. These findings align with a review evidence indicating that speed-endurance training performed with external resistance can improve buffering capacity and the ability of muscles to delay fatigue during high-intensity activities [29].

These results indicate that resisted sprint training with an optimal WV load effectively enhances anaerobic endurance, including PP, AP, and FI. While the study focused on physical performance, this method may also influence technical and tactical skills, such as ball control, passing, dribbling, decision-making, and positioning. Future studies should include these measures, investigate muscle damage and physiological responses (e.g., cytokine modulation), and consider larger sample sizes to evaluate overall soccer performance and potential bone adaptations.

Limitations

This study has several limitations. The sample size was small ($n = 11$ per group), and participants were exclusively amateur males, limiting generalizability. The intervention lasted only three weeks, and retention of the observed improvements was not evaluated. Technical and tactical performance were not measured, and although external training loads were monitored, internal loads (e.g., HR or RPE) were not, so the equivalence of training intensity across groups could not be fully confirmed. Control over participants' nutrition and sleep was also limited. Additionally, some of the greater improvements observed in the group with lower baseline scores may partly reflect regression to the mean, which should be considered when interpreting the results. Nevertheless, all findings regarding improvements in anaerobic endurance remain valid and significant.

Conclusions

WV-based AnST training at $12.40 \pm 0.13\%$ of body weight was the most effective in improving soccer players' anaerobic endurance. Despite lower initial scores, the intervention significantly enhanced PP and AP and reduced FI, indicating that a load of

approximately 12% of body weight elicits more optimal neuromuscular and metabolic adaptations than lighter or unloaded conditions.

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Conflict of Interest

The authors declare no conflict of interest.

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