Does Post-Activation Performance Enhancement (PAPE) occur with strength exercises on unstable surfaces? Effects on jump and sprint performance in a randomized crossover trial

¿Ocurre la Potenciación Post-Activación Estimulada (PAPE) con ejercicios de fuerza en superficies inestables? Efectos en el salto y la carrera en un ensayo cruzado aleatorizado

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Abstract

Introduction: The effect of Post-Activation Performance Enhancement (PAPE) has been investigated using various strength exercises and training equipment.
Objective: This study aimed to assess the effect of dynamic strength exercises on unstable platforms on jump ability and linear speed in jumping athletes and university sprinters.
Methodology: A randomized controlled crossover design was implemented with fifteen athletes from the University of Antioquia. All participants had at least six weeks of training experience, though variability in training years was considered a potential factor influencing results. The study lasted three weeks, with two randomized interventions.
Participants initially completed three familiarization of strength exercises on unstable platforms. Pre-tests measuring 20-meter sprint and countermovement jump were then conducted. Two groups were formed: Group A performed a standard warm-up, while Group B completed three sets of eight repetitions of strength exercises on Bosu with two minutes of recovery. Post-tests were administered at 0, 5, 9, and 12 minutes after intervention. Following a seven-day washout period, groups switched protocols, and tests were repeated. A blinded statistical analyst used repeated measures ANOVA and post-hoc Tukey tests for comparisons, with graphical analysis conducted in R Studio.
Results: Both protocols significantly improved countermovement jump and sprint performance ($p < 0.001$). However, the experimental group exhibited immediate sprint potentiation, whereas the control group experienced it at minute 9 ($p < 0.001$).
Conclusions: Strength warm-ups on unstable platforms produce similar Post-Activation Performance Enhancement effects to stable dynamic warm-ups on neuromuscular variables such as countermovement jump and sprint.

Keywords

Athletics; performance enhancement; resistance training; unstable strength training; warm-up.

Resumen

Introducción: El efecto de la Potenciación Post-Activación Estimulada (PAPE) ha sido investigado utilizando diversos ejercicios de fuerza y equipos de entrenamiento.
Objetivo: Este estudio tuvo como objetivo evaluar el efecto de los ejercicios de fuerza dinámicos en plataformas inestables en la capacidad de salto y la velocidad lineal en atletas de salto y velocistas universitarios.
Metodología: Se implementó un diseño cruzado controlado y aleatorizado con 15 atletas de la Universidad de Antioquia. Los participantes tenían al menos seis semanas de experiencia en entrenamiento, considerando que la variabilidad en los años de entrenamiento podría influir en los resultados. El estudio duró tres semanas, con dos intervenciones aleatorizadas.
Al inicio, los participantes realizaron tres sesiones de familiarización con ejercicios de fuerza en plataformas inestables. Luego, se realizaron pruebas previas para medir la velocidad en 20 metros y el salto en contramovimiento, formando dos grupos: el Grupo A hizo un protocolo de calentamiento estándar, mientras que el Grupo B completó tres series de ocho repeticiones de ejercicios de fuerza sobre Bosu con dos minutos de recuperación. Se repitieron las pruebas a los 0, 5, 9 y 12 minutos después de la intervención. Tras un período de lavado de siete días, se intercambiaron protocolos. Un analista estadístico cegado utilizó ANOVA de medidas repetidas y pruebas post-hoc de Tukey para las comparaciones, con análisis gráfico realizado en R Studio.
Resultados: Ambos protocolos mejoraron significativamente el rendimiento en el salto en contramovimiento y en la velocidad de carrera ($p < 0.001$). Sin embargo, el grupo experimental mostró una potenciación inmediata en la velocidad, mientras que el grupo control la experimentó en el minuto 9 ($p < 0.001$).
Conclusiones: Los calentamientos de fuerza en plataformas inestables producen efectos de Potenciación Post-Activación Estimulada similares a los calentamientos dinámicos estables en variables neuromusculares como el salto en contramovimiento y la velocidad de carrera.

Palabras clave

Atletismo; calentamiento; fuerza en inestables; mejora de rendimiento; rendimiento deportivo.

Introduction

In competitive sports, optimizing performance through specific training strategies is a key concern, as even minor improvements can influence success (Prieske et al., 2020). This study focuses on university-level athletes, exploring methods to enhance neuromuscular performance during warm-up. Even minor differences in neuromuscular performance can significantly impact competitive outcomes (Prieske et al., 2020). This highlights the need for effective activation strategies before performance tests. In this study, we compare a strength-based warm-up on an unstable surface with a standard dynamic warm-up to analyze their effects on sprint and jump performance. Various strategies have been explored to enhance muscular performance in high-intensity, short-duration sports; among them, warm-ups, maintenance of muscle temperature, remote ischemic preconditioning, hormonal preparation, and post-activation potentiation (PAP) have been studied (Kilduff et al., 2013), a term adjusted for sports training as Post-Activation Performance Enhancement (PAPE) (Cuenca-Fernández et al., 2017).

Post-Activation Performance Enhancement (PAPE) differs from Post-Activation Potentiation (PAP) in its measurement approach. While PAP is assessed through laboratory-based muscle contraction speed tests, PAPE is evaluated through observable improvements in physical performance, such as jump height and sprint speed, following a conditioning activity (Prieske et al., 2020). Another notable distinction between these terms is highlighted by Escobar-Hincapié et al. (2021): "PAP reaches its peak around 28 seconds, while PAPE takes effect at 3 minutes, with optimal results between 3 and 7 minutes" (p. 2).

Several systematic reviews, including Wilson et al. (2013) and Seitz & Haff (2016), have explored the effects of post-activation potentiation (PAP), particularly in high-intensity strength exercises (≥60% 1RM). However, there is still debate regarding the role of training experience in balancing fatigue and potentiation effects, as more trained individuals may benefit more from these interventions. Further research is needed to better understand how different warm-up strategies influence performance outcomes. The general conclusions of the two meta-analyses suggest that several exercises with few sets (two or three) and repetitions (less than or equal to six) at high intensity (>70%) are effective for increasing the performance of power exercises such as jumps, sprints, and throws, in well-trained athletes (Boullosa, 2021). PAPE requires conditioning exercises with specific rest periods, load, and volume (Yeow Ng et al., 2020) to stimulate type II muscle fibers especially. Its enhancing effect is supported by physiological responses that include increased muscle temperature, intracellular water accumulation, and motor unit stimulation (Blazevich & Babault, 2019), allowing for immediate subsequent improvement in the neuromuscular system, especially in strength (Beato et al., 2019) and in explosive activities such as jumps and sprints (Cardozo et al., 2019; Prieske et al., 2020).

Various exercise protocols generating the PAPE effect have been investigated, primarily those stimuli involving high-load strength (Petisco et al., 2019), isoinertial pulleys (Beato et al., 2019; Maroto-Izquierdo et al., 2020), unilateral exercises such as unilateral squat (Escobar-Hincapié et al., 2021), resisted sprints, variable load, isometrics, among others (Cardozo et al., 2019; Yeow Ng et al., 2020); however, more evidence is needed to study unstable surfaces as a means to generate PAPE.

A Position Stand from the Canadian Society for Exercise Physiology reviewed various activation strategies and their impact on sports performance, emphasizing the importance of optimizing warm-up protocols to enhance neuromuscular responses. While much of the research referenced in this document focused on post-activation potentiation (PAP), the role of post-activation performance enhancement (PAPE) in different training contexts remains an area for further investigation (Behm et al. 2015), it is recognized that it allows for greater core activation and greater co-activation of antagonist muscles to increase joint stability (Peña et al., 2012). Souto et al. (2009) found greater activation of the lateral, medial, and rectus femoris fibers by 18%, 16%, and 21%, respectively, when performing squats on unstable bases. Additionally, Kean et al. (2006) suggest that an improvement in stability could decrease the proportion of primary motor muscles assigned to stabilization and allow them to favor body propulsion for jumping or running. These same researchers were able to demonstrate significant improvements in CMJ ($p<0.05$; ES = 0.57) but not in t20, after 6 weeks of unstable foot training vs a group that applied functionally directed exercises and a control group, in active recreational women.

Different studies have compared the effect of training on unstable bases with training on stable bases, generally finding that there are no statistically significant differences in some neuromuscular performance variables (Kibele & Behm, 2009; Sparkes & Behm, 2010; Mate-Muñoz et al., 2014; Zuo et al., 2022). Some research has reported slight differences in certain variables in favor of stable training (Zemková, 2020; Cressey et al., 2007) or unstable base training (Lago-Fuentes et al., 2018; Sánchez-Sánchez et al., 2022). These findings demonstrate that contrasting results and inconsistent differences are found in the literature (Behm et al., 2015).

Achieving sporting results in high-performance sports such as athletics often depends on explosive strength, manifested in actions such as jumping and running, where the ability to produce force rapidly is crucial for achieving optimal performance in competitions (Jiménez-Reyes & González-Badillo, 2011); therefore, monitoring performance through jumps and sprints in athletes can be useful for objectively quantifying strength and potential changes in individuals' functional capacities; for example, decreases in lower limb force production that could predict or explain decreases in sprinting and/or possible overtraining (Hébert-Losier & Martin, 2013).

The measurement of jump ability has commonly been used to assess muscle power, becoming an important set of physical capacity tests in sports. The countermovement jump test (CMJ), which measures vertical jump, estimates force production per unit of time, motor unit recruitment, muscle fiber composition, and even elastic energy (Jiménez-Reyes & González-Badillo, 2011); while through linear sprinting, tests exist that measure according to their distance and starting protocol; some start from a standstill, others from a rolling start (with a previously developed velocity). Those measuring short distances (5-10 meters) assess acceleration speed, while maximum speeds are evaluated between 20-40 meters (Darral-Jones et al., 2016).

Given the foregoing, the aim of the study was to determine the effect of PAPE from an unstable base strength exercise compared to a standard dynamic warm-up focusing on joint mobility in university-level jumpers and sprinters. The findings of this research contribute to the field of athletic knowledge, also facilitating improvements in training and performance processes as they may aid in identifying strategies to enhance performance in sports requiring explosive actions, either through pre-competition warm-up protocols or as stimulators of intra-session conditional skills.

Method

This is a quantitative, longitudinal, and experimental study conducted under a controlled and randomized crossover study design. This design allows each participant to serve as their own control, where each participant will receive either the intervention or the control (A or B) in the first period and the alternative in the subsequent period. Depending on the expected duration of the intervention's action, a washout period may be used between periods (Friedman et al., 2015). A three-week intervention was conducted to answer the following research question: What is the effect of Post-Activation Performance Enhancement induced by an unstable base strength exercise compared to a standard warm-up in college jumpers and sprinters on neuromuscular variables such as countermovement jump and 20-meter linear sprint? The PAPE effect was measured after 0, 5, 9, and 12 minutes of post-intervention recovery, assessed through CMJ and t20 tests.

The intervention protocol lasted three weeks: In the first week, anthropometric measurements were taken for all participants, and three familiarization sessions with the unstable base strength protocol were conducted In the second week, CMJ and t20 pre-tests were conducted, dividing participants into two groups (A and B) randomly assigned using simple randomization in Excel. Group B performed the Bosu strength protocol, and Group A performed the standard warm-up (This warm-up consisted of the same exercises performed in the experimental group executed on a stable surface), measuring their effects on CMJ and t20 after 0, 5, 9, and 12 minutes. After a seven days washout period, the groups were crossed (Group A performed the unstable base strength protocol and Group B the standard warm-up), and post-tests were conducted again at the respective times.

Familiarization took place at the athletics track of the University of Antioquia's university city, whose track is made of charcoal. The intervention protocol was carried out in the coliseum of the same university city, with a synthetic floor. Due to unexpected weather conditions, testing sessions had to be conducted on a different surface than during the familiarization phase. The study took place during the rainy season, requiring the relocation of assessments to an indoor facility to ensure participant safety and consistency in test execution. Familiarization sessions consisted of the same intervention protocol used in the study, allowing participants to adapt to the exercises and testing procedures before formal data collection., in a descriptive style.

Participants

The sample size calculation was performed using the study by Escobar-Hincapié et al. (2021) as a reference, where the effect size was 1.2, a sample size ratio of 1, a power of 80%, and a 95% confidence interval (two-sided) were expected, resulting in a sample size of 12 subjects. However, considering a 20% increase, the sample size was determined to be 15. The analysis was conducted using the statistical software EPIDAT version 4.2.

Fifteen athletes, comprising 13 males and 2 females. All participants were in good health, as determined by a pre-participation health questionnaire. This questionnaire screened for recent injuries, musculoskeletal disorders, or medical conditions that could affect physical performance. Participants with any of these conditions were excluded from the study. No formal medical examination was conducted, of legal age, mostly jumpers and sprinters (11), from the University of Antioquia, with regular athletics training at least three times a week for six weeks, voluntarily participated in the study.

Participants were university-level athletes with varying anthropometric characteristics. A detailed statistical summary of participant demographics is provided in the Results section. Informed consent forms were signed, where subjects were informed of the benefits, potential risks, and their right to withdraw from the study at any time they deemed appropriate. The study procedures were conducted following the principles established by the Declaration of Helsinki and were approved by the Ethics Committee of the University of Antioquia (Approval Code ACEI 35-2023).

Procedure

Article text. The intervention lasted for three weeks, taking into account the factors to consider in the design of PAPE studies established by MacIntosh (2012).

During the first week, all participants gathered for anthropometric measurements to obtain data on weight, height, and neck circumference. Additionally, they were asked about their experience in the practiced athletics modality and their duration of involvement. From that first day and on the following two consecutive days, all participants underwent three familiarization sessions to perform the standard warm-up protocol (similar to that of Maroto-Izquierdo et al., 2020) which consisted of five minutes of dynamic mobility (leg swing, dorsi-plantiflexion of the ankle, lateral hip swings, heels, squats and advanced) of 20 seconds for each exercise and repeating it twice in stable surface; then they executed the strength exercise on Bosu (Half squat, 3 sets of 8 repetitions with 2 minutes of recovery) and the execution of the tests (CMJ and t20) at minutes 0, 5, 9 and 12.

At the beginning of the following week, pre-tests for CMJ and t20 were conducted, the results of which allowed for the formation of two groups (A and B) randomly assigned using simple randomization in Excel. Immediately after, Group B performed the Bosu strength protocol, while Group A underwent the protocol with the standard warm-up, followed by measuring their effects on CMJ and t20 after 0, 5, 9, and 12 minutes (post-tests).

Subsequently, a washout period of seven days was allowed, A 7-day wash-out period was implemented between conditions to avoid carry-over effects. This duration was chosen based on physiological recovery principles and methodological consistency in crossover designs. Previous research suggests that neuromuscular adaptations can persist for several days after activation protocols, potentially influencing performance responses if an adequate recovery period is not established (Blazevich & Babault, 2019). Additionally, in previous post-activation studies, recovery periods ranging from 48 hours to 7 days have been used in similar experimental designs to minimize interference between conditions (Till & Cooke, 2009). A one-week interval was selected to ensure full recovery while maintaining the study's practical feasibility. The groups were crossed, so that in the following week, interventions alternated between groups (Group B received the standard warm-up protocol and Group A the Bosu strength protocol), with their effects on CMJ and t20 re-evaluated at the aforementioned times.

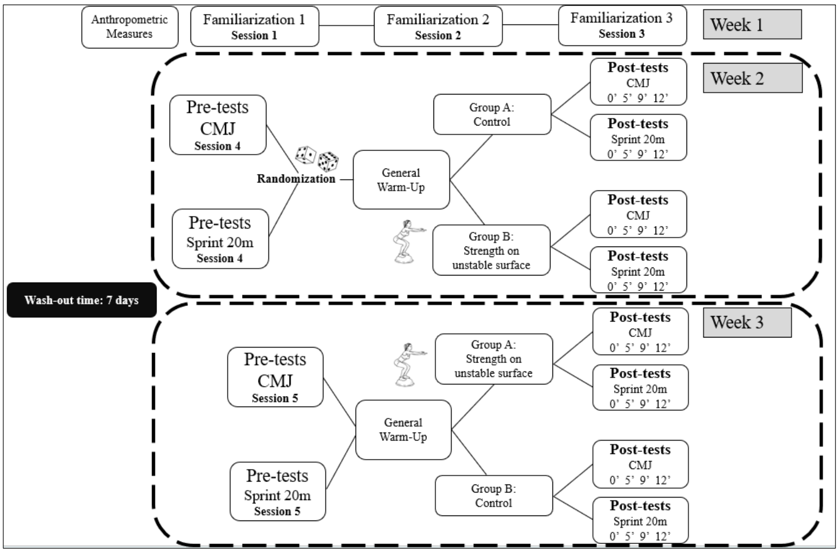
Vertical jump performance was assessed using the Countermovement Jump (CMJ) test, measured with Chronojump contact platforms (Bosco System). Chronojump has demonstrated high validity and reliability for measuring vertical jump height, with an intraclass correlation coefficient (ICC) of 0.98 and a coefficient of variation (CV) below 3% (Castagna et al., 2013). Each participant performed five CMJ trials, and the highest and lowest values were discarded. The final jump height was calculated as the average of the remaining three jumps.

Sprint performance was assessed using a 20-meter sprint test, recorded with high-speed cameras operating at 240 Hz. High-speed video analysis has been validated as a reliable method for measuring sprint time, with an ICC above 0.95 and minimal systematic error (Haugen et al., 2012). Each participant performed three sprint trials, with the best time used for analysis.

Randomization

After the CMJ and t20 pre-tests, the groups were assigned using the simple randomization method, employing Microsoft Excel software version 16, thus allocating the experimental and control groups to carry out the respective interventions (see Figure 1).

Figure 1. Protocol used for the intervention.



Note. Countermovement jump (CMJ)

In the second week, pre-tests were conducted for each participant. The CMJ was measured using a Chronojump Bosco-system contact platform, validated by Pueo et al. (2018), showing a correlation of r= 1.00; thus, concluding that the system exhibits high stability, with CV (Coefficient of variation) values of 0.01%. The t20 was assessed using the My Sprint application, recording a video of each sprint and measuring the time between signals marked every 5 meters through the application. This instrument was validated with nearly perfect correlation between time values for each sprint split compared to photocells (r= 0.989–0.999, standard error of estimation =0.007–0.015 s, ICC = 1.0) by Romero-Franco et al., 2017.

With this information, a simple randomization was conducted via Excel to obtain two balanced groups (A and B). Subsequently, both groups executed the standard warm-up protocol. Following this, participants performed a series of three jumps on the contact platform to determine the CMJ (selecting the best for analysis) and a 20-meter linear sprint measured with the My Sprint App. Thus, Group A, which only performed the warm-up, immediately underwent post-tests at minutes 0, 5, 9, and 12, while Group B proceeded to execute the half-squat on Bosu (3 sets of 8 repetitions at maximum effort in the concentric phase of leg extension with a 2-minute recovery interval) and then underwent post-tests at the mentioned times (see Figure 1).

In the following week, with a 7-day washout period and maintaining randomization in groups A and B, the pre-tests were conducted again to apply the opposite interventions from the previous week (crossing them), so that Group B only performed the warm-up protocol and Group A underwent both the warm-up and the unstable surface strength protocol. Subsequently, in both groups, the post-tests for linear sprint and countermovement jump were conducted at 0', 5', 9', and 12'.

Data analysis

An analysis of data distribution was conducted using the Shapiro-Wilk statistical test, which revealed that the data were normally distributed. Therefore, parametric statistics were employed for all variables, utilizing means and standard deviations for data description. Firstly, an intra-group analysis was performed for each group using an ANOVA of repeated measures, both for CMJ and the 20-meter linear sprint test. Additionally, a post-hoc test was conducted, in this case using Tukey's test, carried out with the statistical software Jamovi 2.3.21. Then, inter-group comparisons were made using ANOVA, and the graphs were generated using R studio software. The behavior of the groups was overlaid on the graphs, with individual group behaviors depicted for visual comparison. Statistical significance was set at $p < 0.05$.

Results

Participants characteristics

Participants had an average age of 26.6 years (±8.93), height of 1.75 m (±0.09), body mass of 69.77 kg (±8.87), and a BMI of 22.77 kg/m² (±1.97). Table 1 presents the sociodemographic descriptors of the study participants. If you use tables and figures (table 1), you should take into account the following indications.

Table 1. Sociodemographic descriptions

Weight (kg)	Size (m)	BMI (kg/m²)	AGE (years)	EXPERIENCE TIME (years)
69.77 (8.87)	1.75 (0.09)	22.77 (1.97)	26.6 (8.93)	4.47 (3.94)

Note. Body mass index (BMI)

After conducting the normality test using the Shapiro-Wilk test and identifying a normal distribution in the variables, it was decided to employ parametric statistics. Firstly, an intra-group analysis was conducted using repeated measures ANOVA for both CMJ and the linear sprint. Subsequently, repeated measures ANOVA was applied to both independent variables for the control group, which underwent the standard warm-up protocol as well as for the experimental group that performed the unstable base strength protocol (Table 2).

As observed in the following table, statistically significant differences are detected in all four analyses through repeated measures ANOVA (in experimental and control groups, in sprints and CMJ´s).

Subsequently, a post-hoc analysis is conducted using Tukey's test. Table 2 presents this analysis for the CMJ and sprint in the control and experimental groups.

Figure 2. Between- and within-group results using a 2x2 ANOVA; including percentage changes and effect sizes

Experimental group						IC 95%		Control group					IC 95%		Interaction between groups	
Tiempo	Pretest (S.D.)	Postest (S.D.)	%	P (Tukey)	ES	Inf	Sup	Pretest	Postest	%	P (Tukey)	ES	Inf	Sup	Postest	P (Tukey)
CMJ 0	35,22 (7,08)	38,12 (8,51)	7,6%	0.027*	0.308	-0.422	1.027	35,84 (6,92)	38,76 (8,49)	7,5%	0.011*	0.440	-0.301	1.167		0.782
CMJ 5	35,22 (7,08)	38,16 (8,14)	7,7%	0.024*	0.304	-0.426	1.023	35,84 (6,92)	39,15 (8,25)	8,5%	0.004*	0.515	-0.234	1.246		0.928
CMJ 9	35,22 (7,08)	37,76 (8,20)	6,7%	0.039*	0.234	-0.491	0.951	35,84 (6,92)	38,86 (8,20)	7,8%	0.012*	0.491	-0.255	1.221		0.979
CMJ 12	35,22 (7,08)	37,53 (8,58)	6,1%	0.038*	0.324	-0.407	1.043	35,84 (6,92)	38,96 (7,79)	8%	0.013*	0.390	-0.347	1.113		0.658
SL20m 0'	3,22 (0,19)	3,12 (0,17)	-3,3%	0.016*	-0.516	-1.248	0.233	3,22 (0,22)	3,12 (0,22)	-3,3%	0.053	-0.521	-1.254	0.228		0.775
SL20m 5'	3,22 (0,19)	3,15 (0,20)	-2,4%	0.201	-0.258	-0.975	0.469	3,22 (0,22)	3,17 (0,25)	-1,8%	0.301	-0.377	-1.100	0.358		0.607
SL20m 9'	3,22 (0,19)	3,15 (0,18)	-2,3%	0.229	-0.404	-1.128	0.334	3,22 (0,22)	3,08 (0,26)	-4,8%	0.035*	-0.622	-1.363	0.139		0.378
SL20m 12'	3,22 (0,19)	3,18 (0,23)	-1,4%	0.767	-0.252	-0.970	0.474	3,22 (0,22)	3,16 (0,22)	-2,2%	0.244	-0.271	-0.989	0.456		0.730

Note. Countermovement jump in centimeters (CMJ); 20 meters linear sprint in seconds (SL20m); confidence interval (IC95%); percentage difference (%); standard deviation (SD); effect size (ES); significance value ($p \leq 0.005$)

It is noted that there is a statistically significant difference between the pre-test and the rest of the post-tests in CMJ, indicating an increase in vertical jump height after the standard warm-up and experimental group. (Figure 3).

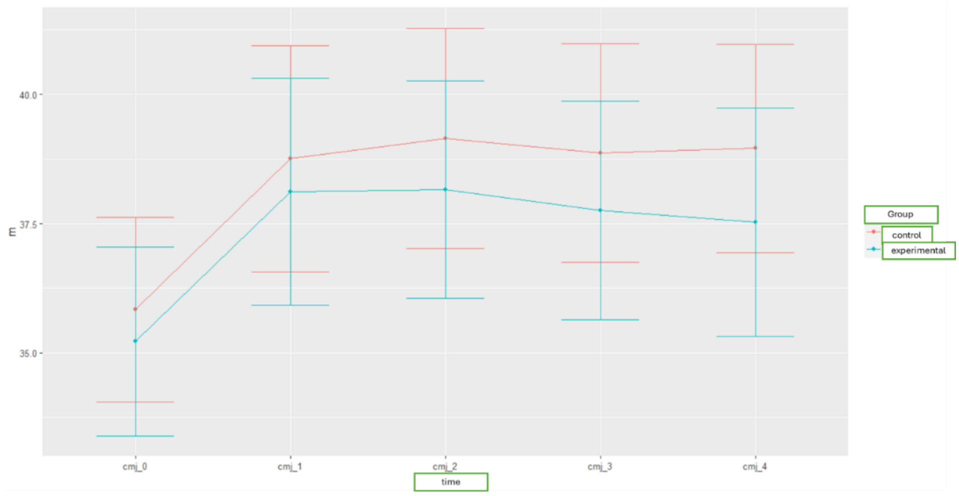
The same analysis is conducted for the 20-meter linear sprint, where significant differences are observed between the time in the pre-test and the time at minute 9 (in control group), indicating a statistically significant decrease in time (increase in performance) after 9 minutes of the standard warm-up.

For the experimental group the CMJ, a significant increase in jump height is observed when comparing the pre-test with the rest of the post-tests, thereafter none of the post-tests show significant differences among them. For the sprint in the experimental group, there were statistically significant differences in the pre-test compared to the first post-test, indicating an immediate potentiation effect; however, no significant differences were observed in the other interactions.

Then, an analysis was conducted using ANOVA between groups, both for the CMJ (Figure 2) and the 20-meter linear sprint (Figure 4). In this analysis, it is observed that there are no significant differences at any time between the groups.

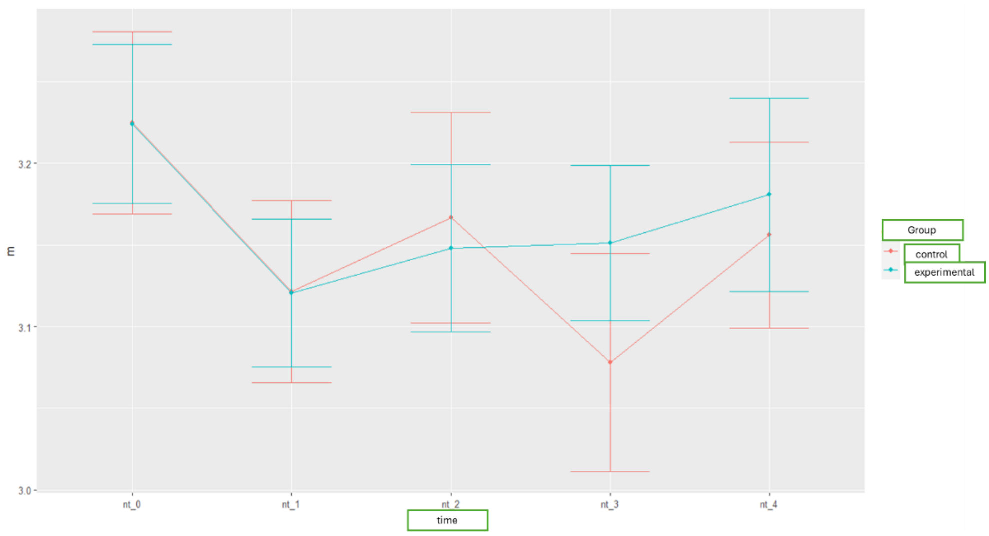
The following figures illustrate the performance trends in the groups, providing a more visual comparison.

Figure 3. Interaction between groups in the various CMJ measurements (in centimeters)



Source: Own elaboration

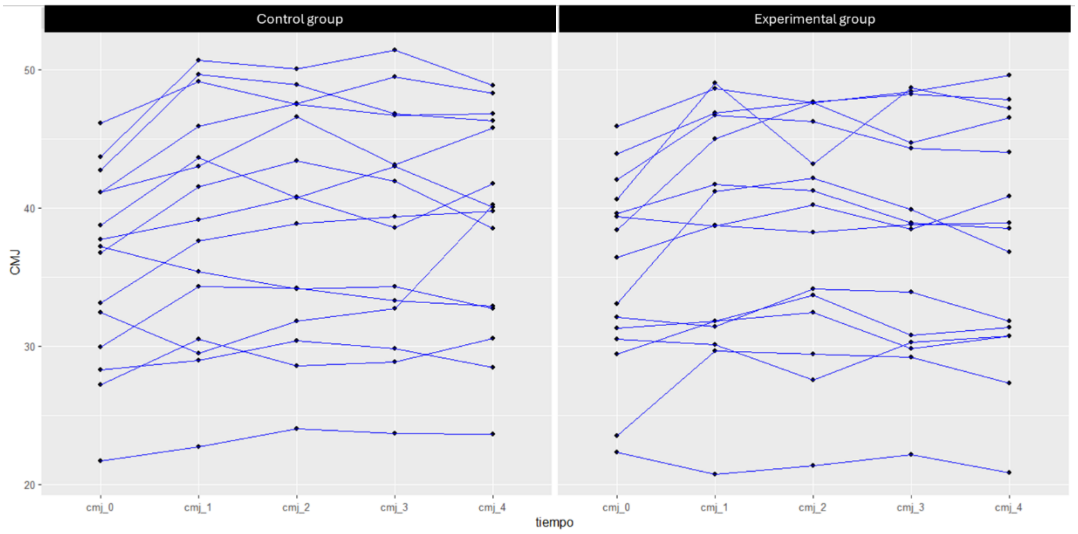
Figure 4. Interaction between groups in the various sprint measurements (in seconds).



Note: Time number (NT).
Source: Own elaboration

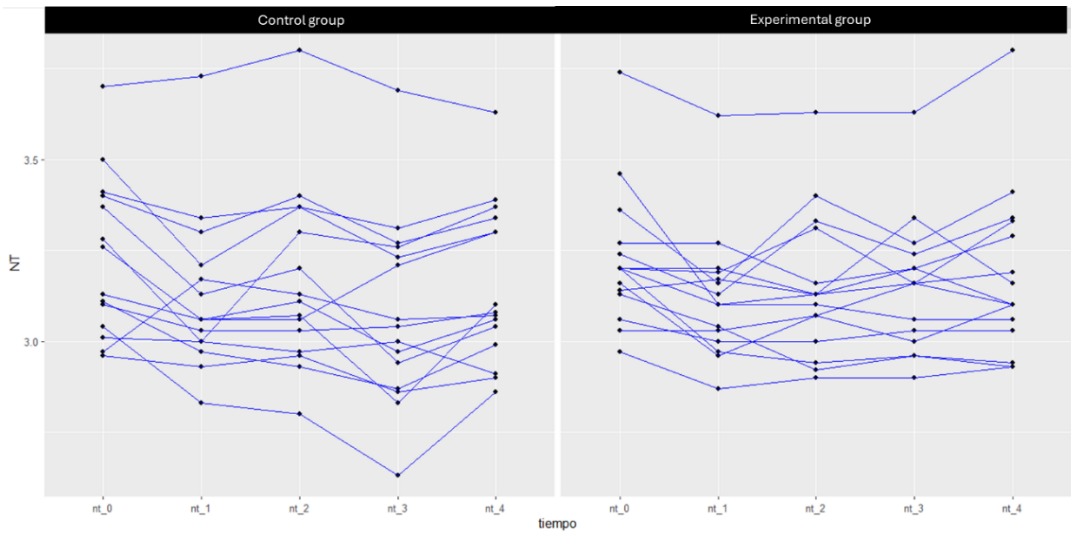
Individual performance in both tests was also graphed for both groups, as shown in Figures 5 and 6.

Figure 5. Individual performance of CMJ (in centimeters) by group



Source: Own elaboration

Figure 6. Individual performance of sprint (in seconds) by group



Source: Own elaboration

Discussion

The aim of this study was to determine the PAPE effect of an unstable surface strength exercise compared to a standard warm-up on CMJ and t20 in sprinters and jumping college athletes. It was found that both protocols significantly improved CMJ and sprint performance at 0, 5, 9, and 12 minutes. (ANOVA CMJ Control Group; F=7.75; p< 0.001) (ANOVA CMJ Experimental Group; F=7.23; p< 0.001). However, the experimental group exhibited an advantage in sprint performance with an immediate potentiation effect from minute 0 (ANOVA Control Group Sprint; F=3.85; p< 0.008), while the group following the standard warm-up protocol had to wait until minute 9 to experience the benefit of potentiation (ANOVA Control Group Sprint; F=6.05; p< 0.001). indicating that unstable base training is unlikely to offer any advantage in PAPE respect traditional strength exercise.

To date, no articles evaluating the PAPE effect using unstable surfaces had been found; however, there are studies comparing the effects of unstable surface training programs with stable surface strength programs, showing contrasting results and inconsistent differences, mostly not significant, very similar to the results of this research. In a meta-analysis conducted by Behm et al. (2015), the effects of unstable surface training versus stable surface or control group training on muscle strength, power, and balance in healthy individuals of different age ranges were evaluated, analyzing 22 articles. As a result, slightly superior effects in favor of unstable surface training on muscle strength were obtained (mean SMDb = 0.15, I2 = 68%, χ 2 = 46.92, df = 15, p<0.001; however, according to the researchers, and after corroborating it with a forest plot, this slight superiority is not consistent. In a systematic review conducted by Zech et al. (2010), the effectiveness of training for neuromuscular control and functional performance, including balance training (some exercises on unstable surfaces), was evaluated, analyzing 20 randomized clinical trials in healthy and physically active individuals, finding that despite controversial findings for jump and agility performance, balance training on unstable surfaces could have some effect to improve those variables; while there were discrepant findings or absence of effect on speed performance.

Other researchers found similar conclusions. A study by Zemková (2021) in recreational participants analyzed differences in force-velocity production under stable and unstable conditions in bench press and squat exercises; concluding that muscle power is affected on unstable surfaces with heavier weights at slower speeds, although no significant differences (p>0.05) were found at higher speeds under unstable conditions compared to stable conditions. Muscle power could be affected by central muscle stiffness affecting movement pattern execution and force production variability of the muscle groups involved in the action. Comparing six weeks of training with the same strength exercises performed on stable and unstable surfaces such as squats, deadlifts, lunges, flat bench press, and kettlebell swings (which they referred to as functional in their study), Zuo et al. (2022) found that in untrained young individuals, there were no statistically significant differences between the two protocols in CMJ (ES= -0.17, p= 0.483), CMJ power (ES= 0.04, p= 0.753), 20-meter sprint (ES= 0.00, p= 0.343), and the medicine ball throw (ES= -0.18, p= 0.513).

Some studies have also reported non-significant differences but with small benefits favoring unstable surface protocols. In a study by Sparkes & Behm (2010), comparing the effects of stable and unstable surface training over eight weeks in active recreational individuals, the group performing strength training on unstable surfaces showed a significantly greater distance (38.4%, p<0.0001) in medicine ball throwing compared to the group training on stable surfaces. Although the unstable group showed a 5.7% improvement in countermovement jump (CMJ) height compared to 1.5% in the stable training group, these differences were not statistically significant (p= 0.09). The authors concluded that training on unstable surfaces can improve strength and balance in untrained youth similarly to machine training using heavier loads; this could be due to improvements in muscle cross-sectional area and neuromuscular coordination, the latter favored mainly by unstable surface training (neural adaptations) (Behm et al., 2010). Later, Mate-Muñoz et al., (2014) conducted a 7-week study with 36 untrained men, comparing traditional strength circuit training with unstable surface circuit strength training (using materials like Bosus and TRX) and a control group that did not undergo any training protocol. Both training programs resulted in significant improvements in neuromuscular variables such as One Repetition Maximum (RM), Squat Jump (SJ), and CMJ; however, the group using unstable materials showed slightly superior effects CMJ (17.7% vs 15.2%), SJ (22.1% vs 20.1%), and RM in squat (13% vs 12.6%), leading researchers to suggest that training with unstable materials can be as effective as a stable program, offering a potentially interesting option for improving athletic performance in strength, power, speed, and jumping ability; similarly to the findings of this study.

In contrast to the aforementioned findings, other research has reported improvements in protocols developed under stable conditions with significant differences. Cressey et al. (2007) determined the effect of 10 weeks of lower-body strength training on unstable surfaces on athletic performance markers such as CMJ and linear sprinting at 10 and 40 yards in soccer players (18 to 23 years old). It was found that power in the CMJ had a percentage change of 2.4% when performed under stability, whereas under instability it was 0.0%, with a statistically significant difference between both groups (p<0.05); regarding the 10-yard linear sprint, stable-based training had a percentage change of -7.6% and unstable training was -4%, while in the 40-yard linear sprint it was -3.9% and -1.8% respectively, concluding that similar interventions could demonstrate that lower-body strength training under instability could affect athletic performance variables; the authors suggest that this is due to the reduction in the stretch-shortening cycle capacity, crucial in various sporting actions. In a publication by Granacher et al. (2015), the effect of eight weeks of plyometric jumps on stable versus unstable surfaces in young soccer players was investigated, finding that the CMJ had superior and significant improvements on a stable base (Δ13%, $p<0.001$, f= 1.69) compared to the unstable protocol (Δ4%, p= 0.003, f= 1.17), while the 30-meter linear sprint showed no statistically significant differences (F 1.46=3.17, p= 0.089, f= 0.38).

Saeterbakken et al. (2019) found contrasting results in physically active individuals. CMJ height improved much more after seven weeks of intervention in an unstable board strength protocol (F = 4.304, p =0.010) than in two stable weight-based strength protocols (machines and free weights) (F = 0.046–1.416, p values between 0.251 and 0.831). The squat 10RM had a similar improvement in all three protocols (p< 0.001, ES = 0.14–1.24), as did muscle thickness (p values < 0.001 to 0.049, ES =0.14–0.45); while other variables such as maximum voluntary isometric contraction and rate of force development were higher in a stable base.

Hammami et al. (2016) evaluated adolescent soccer players over eight weeks, finding that four weeks of balance training on unstable surfaces followed by four weeks of plyometric training improved eight out of 13 performance variables with a relative improvement of 22.4% (d = 1.5) vs. 15.0% (d = 1.1) of a protocol that first performs 4 weeks of plyometric training and then 4 weeks of balance on unstable surfaces (reversing the protocol). Variables such as CMJ (Δ14.3% vs Δ8.6%, p = 0.296), RSI (Δ21.5% vs Δ4.8%, p = 0.008), horizontal jump (Δ18.6% vs Δ16.8%, p= 0.531), and agility (Δ-2.2% vs Δ-1.4%, p= 0.631) showed greater improvements when balance training on unstable surfaces was performed first followed by plyometrics than vice versa.

A study by Chaouachi et al. (2017) evaluated the effects of a combination of strength training on unstable surfaces (squats, lunges, glute bridge on Bosu, etc.) and plyometrics in the same session over eight weeks with young soccer players. It was concluded that the combination of both significantly improves strength, power, speed, agility, and balance; however, there were no statistically significant differences ($p>0.05$) when performed alternately or in blocks of work for each protocol. Nevertheless, in the post-tests, greater improvements were reported when exercises were performed first in block than when alternated: CMJ (Δ25%, Δ20%), RSI (Δ66%, Δ51%), Sprint 10m (Δ-7%, Δ-4%), Sprint 30m (Δ-4%, Δ-2%). According to the results of this study, it would seem that there is a potentiating effect of strength exercises on unstable patients in neuromuscular variables such as jumping and linear sprinting, although if they are not significant.

Limitations

Regarding the study's limitations, one of them was the participants' level (college level) who had a very large standard deviation in experience time (±3.94 years). Another limitation was the type of flooring, which, due to logistical problems with the venue, had to be modified for some participants, despite being conducted in the same coliseum. An important limitation was the absence of evaluation of Bosu pressure level since it is an aspect that does not allow identifying instability level accurately, potentially compromising the external validity of the study.

Always performing the test in the same order (jump first and then sprint) may represent a bias, as the action of the three CMJs can potentiate the 20-meter linear sprint.

Conclusions

Both the standard warm-up and the warm-up on an unstable surface produce significant gains in countermovement jump height from minute 0 to 12. However, an improvement in sprint performance is only observed in the group subjected to the intervention on an unstable surface, showing a significant enhancement from minute 0, whereas the standard warm-up group showed improvements only at minute 9.

Few studies have investigated the effect of training on unstable surfaces on different neuromuscular performance variables; therefore, further studies in different populations are encouraged to increase the body of evidence that allows for decisive conclusions on the topic.

Practical applications

According to the results of this study, it is plausible to employ both protocols as activation strategies before engaging in neuromuscular activities involving countermovement jumps and/or linear 20-meter sprints. The use of strength exercises on unstable surfaces could serve as an alternative proposal for pre-activation and warm-up routines.

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