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Acute Effects of Different Warm-Up Protocols on Jump Performance in Elite Male Italian Handball Players

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Abstract: The aim of the present study was to evaluate the acute effects of three different warm-up protocols on jump performance in elite male handball players. Warming up with a traditional (TR) set of exercise was compared with balance (BA) and unbalanced (UN) activation protocols. Thirty-two male handball players (age 24.2 ± 4.7 (m ± SD) y, weight 84.4 ± 8.5 kg, height 183.9 ± 7.3 cm) from two Italian first division National championship teams completed the three warm-up protocols in three different occasions and performed three countermovement jumps each with a 3 min rest. The jump height was evaluated from flight time. The players jumped an average of 40.7 ± 4.8 cm, 42.4 ± 4.9 cm, and 42.5 ± 5.0 cm in TR, BA, and UN conditions, respectively. A significant main effect ($p < 0.001$; $\eta^2 = 0.812$) between the warm-up protocols for jump height was detected. A post hoc analysis showed that athletes performed significantly higher jumps under BA ($p < 0.001$) and UN ($p < 0.001$) conditions compared to performing a TR warm-up protocol. In conclusion, both BA and UN warm-up protocols induced significantly higher jump heights in elite male Italian handball players, compared to the traditional warm-up routine. The use of dynamic activation exercises enhance the neuromuscular properties of the warm-up compared to traditional protocols.

Keywords: countermovement; activation; balance; core; bosu

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1. Introduction

Handball is an intermittent sport that primarily uses aerobic metabolism, alternating by high-intensity actions supported by anaerobic metabolism [1]. Specific technical movements are required to handle the wide range of tactical situations in the game. Repeated jumps, sprints, and changes in direction and many high-speed body contacts make handball one of the fastest and most intense team sports. Unlike other situational sports, high-intensity actions in handball do not involve running at high speed, but rather short and explosive actions, such as jumps, stops, unbalances, changes in direction and duels [2]. To effectively and successfully perform these technical actions, it is necessary to excel in explosiveness and power in the lower limbs [3]. The expression of these muscular qualities can be easily appreciated by monitoring the vertical jump performance of the athletes throughout the season. Moreover, jump tests can be used to evaluate recovery and readiness and to optimize performance peaks [4].

During the game, athletes are often required to jump as high as possible, such as in overhead shots, defensive blocking, and intercepting fly passes [5]. Many of these actions are performed off balance, so during training this ability is engaged since the initial dynamic activation warm-up phase. Most jumps are performed by taking off with two legs, although some jumps are performed in single leg, such as some overhead shots and dive shots. Therefore, in handball research, vertical jump performance is often used to determine the effects of a training protocol [6–16] and the relationships between physical features, key performance indicators [3,17], and trends in post-exercise recovery [18,19].

To achieve a high level of performance in competition, several specific warm-up protocols have been developed for handball players. Acute effect of static compared to dynamic stretching [20–22], as well as traditional warm-up protocols, has been investigated [23]. The evidence indicates that dynamic stretching is more effective than static stretching. In addition, the use of elastic bands and unstable surfaces is preferred over traditional warm-up protocols. The optimal duration of warm-up protocols was also investigated by Romaratezabala and colleagues [24], as well as the optimal recovery period between warm-up and performance [18–25]. The duration of the warm-up protocols was found to be statistically insignificant. However, the 12 min warm-up was demonstrated to be more effective than the 8 and 4 min warm-ups in maintaining optimal readiness for physical testing. In addition, several of these protocols have been compared to identify the best strategies to improve performance in sprints [26], jumps [23,26,27], and shooting skills [23,28]. The use of elastic bands on unstable surfaces has been shown to be the most efficacious approach for the warm-up of high-level professional athletes to improve jump and sprints ability, and shooting skills.

Testing the effect of new warm-up strategies becomes necessary to cope with the evolution of training methodologies to maximize performance. Hence, the aim of this study was to evaluate the acute effects of three different warm-up protocols on jump performance in elite male handball players. We hypothesized that warming up with a traditional warm-up approach was different from performing an activation protocol on a stable or an unstable surface in terms of neuromuscular readiness. The novelty of this scientific research is the combination of previous studies in a single experimental design and the testing of the effects of these warm-up protocols on high-level athletes, on whom very few studies have been conducted.

2. Materials and Methods

2.1. Experimental Approach to the Problem

Based on previous data [23], the required sample size was determined using G*Power 3.1.9.7 software for an a priori power analysis of a one-way ANOVA (fixed effects, omnibus test). The analysis assumed the following: α (significance level): 0.05; power ($1 - \beta$): 0.95; number of groups: 3; Effect Size, f: 0.815. The result indicated a total sample size of 27 participants. After three familiarization sessions (1 week before the first experimental visit), a within-subject crossover design was used to examine the effects of 3 different warm-up protocols on subsequent vertical countermovement jump performance. Three different warm-up protocols were performed in different training weeks in a random order, the first training session of the week in the pre-competitive preparation period. The 3 warm-up protocols analyzed were traditional sports warm-up, mainly build up on running patterns (TR), warm-up with balanced lower-limb and core activation exercises (BA), and warm-up with unbalanced lower-limb and core activation exercises performed on an unstable surface (UN). After each warm-up protocol, subjects were evaluated in countermovement jumping performance. All the warm-up protocols were carefully designed before the training sessions and conducted under the supervision of the strength and conditioning coach. The testing assessment was performed by one of the authors of this study.

2.2. Participants

Thirty-two male handball players (age 24.2 ± 4.7 (m ± SD) y, weight 84.4 ± 8.5 kg, height 183.9 ± 7.3 cm, experience 9.7 ± 5.8 y) from 2 Italian first division national championship teams, volunteered to participate in this research. After an explanation of all procedures, risks, and benefits, each participant provided a written informed consent to participate in the present investigation.

Exclusion criteria were injuries that occurred in the year before the study. Inclusion criteria require participants to have at least 3 years' experience in handball training. This kind of warm-up routine is usually performed by all players positions, and thus, all players (goalkeepers *n* = 6; center backs = 4; backs *n* = 9; wings *n* = 9; pivot *n* = 4) were included in the present research. Participants were asked to fully abstain from alcohol, caffeine, vigorous physical activity, and resistance training for at least 48 h before the tests. All training and testing sessions were performed on the same day of the week, approximately at the same time of the day and under similar environmental conditions. All other training-related contextual factors (social behavior, cultural factors, psychological approach) were strictly maintained between test sessions. This study was previously approved by the institutional board of the University of Bologna (protocol ID: 0369536, 25 November 2021), and all the experimental procedures in this investigation were in accordance with the Declaration of Helsinki.

2.3. Procedures

2.3.1. Warm-Up Intervention

The three warm-up protocols had an identical number of exercises and total duration (5 min). In TR condition, a traditional warm-up consisting of aerobic exercises built up on different running patterns (shuffle, high knees, and butt kicks) and dynamic walking hamstring and quadriceps stretches was performed. Contrariwise, BA condition included a set of bird dogs, dynamic front planks, dynamic side planks, backward lunges, and single-leg squat jumps [29,30]. Finally, in the UN condition, the same exercises of the BA were performed on an unstable surface, specifically a bosu. The exercises of the BA and the UN conditions are depicted in Figure 1.

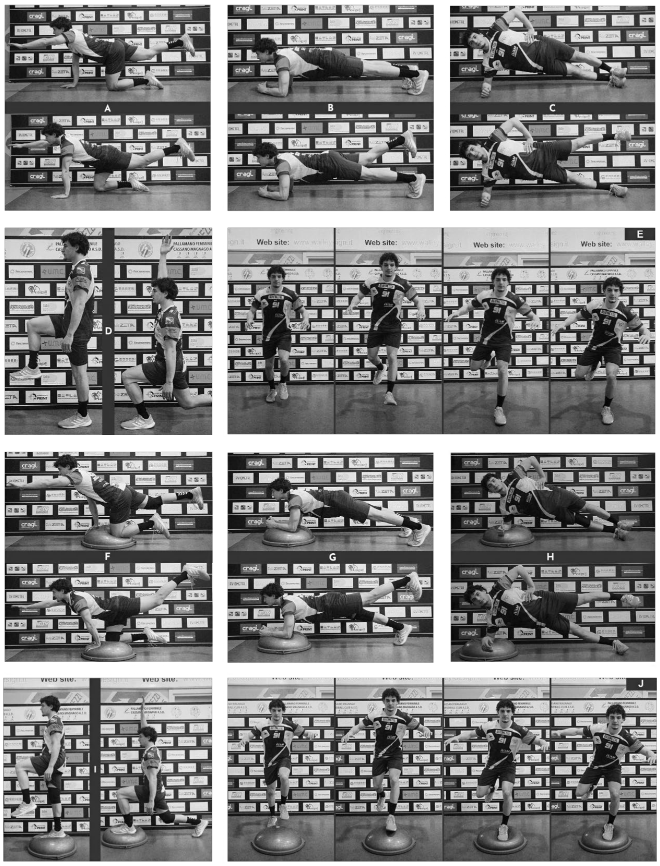

Figure 1. Exercise performed in the BA and the UN conditions, on ground and on bosu, respectively: bird dogs (**A**,**F**), dynamic front planks (**B**,**G**), dynamic side planks (**C**,**H**), backward lunges (**D**,**I**), and single-leg squat jumps (**E**,**J**).

2.3.2. Measurements

During the execution of the warm-up protocols, a researcher supervised the execution time of each subgroup of exercises and the total time. After each of the three warm-up protocols, participants performed 3 countermovement jumps with a 3 min rest between each jump. All players performed all three warm-up protocols. They were required to keep their hands on their hips and were asked to maximize their jump height. Test procedures were fully explained to each subject before each attempt, and data were collected by one of the researchers. This test is commonly used in the assessment of elite sports performance, and hence, all the participants of the study were very familiar with countermovement jump normative procedure, the test participants having 9.7 years on average of high-level handball playing experience. The trial with the highest jump height was recorded for data analysis into a Microsoft Excel spreadsheet. Jump height was evaluated from flight time measured using the Optojump photocell system (Microgate, Bolzano, Italy). The tests were performed on the playing field and while wearing playing shoes.

2.4. Statistical Analysis

A Shapiro–Wilk test was used to test the normal distribution of the data. Data were analyzed using a one-way repeated measures analysis of variance (ANOVA) to evaluate differences between conditions (TR, BA, UN), using R statistical software, version 4.2.2 (R Core Team (2022); R is a language and environment for statistical computing; R Foundation for Statistical Computing, Vienna, Austria). In the event of a significant F ratio, Bonferroni post hoc tests were used to determine pairwise differences. For effect size, the partial eta squared statistic was reported according to Stevens et al., where 0.01, 0.06, and 0.14 represent small, medium, and large effect sizes, respectively [31]. All data are reported as mean ± SD. A significance level of $p \leq 0.05$ was set for all analysis.

3. Results

The players jumped an average of 40.7 ± 4.8 cm, 42.4 ± 4.9 cm, and 42.5 ± 5.0 cm in the three experimental conditions TR, BA, and UN, respectively. The Shapiro–Wilk test was non-significant in all three conditions, with *p*-values of 0.078, 0.139, and 0.129 for TR, BA, and UN, respectively. More details are depicted in Table 1.

Table 1. Descriptive statistic of the counterbalanced jump test performed in TR (traditional sports warm-up), BA (warm-up with balanced lower-limb and core activation exercises), and UN (warm-up with unbalanced lower-limb and core activation exercises performed on an unstable surface) conditions. In addition, Shapiro–Wilk normality test details were reported.

Condition	Jump Height [cm]	SD	Statistic (W)	Sig. (*p* Value)
TR	40.7	4.8	0.94057	0.0777
BA	42.4	4.9	0.94943	0.1389
UN	42.5	5.0	0.94932	0.1291

SD means standard deviation. Significant differences values at $p < 0.05$.

Although the normality assumption is satisfied by the Shapiro–Wilk test, the same cannot be said for sphericity. In addition, Mauchly's W sphericity test was slightly significant, with a *p*-value of 0.043, so Greenhouse–Geisser correction was applied to the analysis of variance. More details are depicted in Table 2.

Table 2. Mauchly's W Sphericity Test details were reported.

	Mauchly's W	Sig. (p Value)				
	0.81	0.043 *				
Sphericity Corrections	GG	DF [GG]	Sig. (p value)	HFe	DF [HF]	Sig. (p value)
	0.841	1.68, 52.12	<0.001 *	0.883	1.77, 54.77	<0.001 *

GG means Greenhouse–Geisser; DF means degree of freedom; HFe means epsilon of Huynh–Feldt test; * significant differences values at $p < 0.05$.

The ANOVAs showed that there was a significant main effect ($p < 0.001$; $\eta^2 = 0.812$) between the warm-up protocols for jump height. A post hoc analysis showed that athletes performed significantly higher jumps after BA ($p < 0.001$; d = −3.220) and UN ($p < 0.001$; d = −2.318) conditions, with respect to TR warm-up protocol. No significant difference was found between the jump height performed after BA and UN. Details of the analysis of variance and post hoc test are included in Table 3.

Table 3. ANOVA table and post hoc outcomes are depicted.

ANOVA	DF	F	Sig. (p Value)	η_p^2	
Main Effect	2	133.543	<0.001*	0.812	
Post Hoc Comparisons	F	Mean diff. [95% CI]	p	Corrected p	Cohen's d
BA-TR	−18.2	−1.650 [−1.879; −1.421]	<0.001 *	<0.001 *	−3.220
BA-UN	−0.805	−0.106 [−0.440; 0.228]	0.427	1	−0.142
TR-UN	−13.1	−1.650 [−2.095; −1.417]	<0.001 *	<0.001 *	−2.318

ANOVA means analysis of the variance; DF means degree of freedom; η_p^2 means partial eta squared; corrected p means that p value has been corrected following Bonferroni's procedures; * significant difference values at $p < 0.05$.

4. Discussion

The main finding of this research was that both BA and UN warm-up protocols induced significant different jump heights in elite male Italian handball players, compared to the traditional warm-up routine. Jumps performed after the UN warm-up protocol were slightly better, though not significantly so, than those performed after the BA protocol. However, the lack of significant differences in jump height between the BA and UN warm-up protocols suggests that both protocols were equally effective in eliciting improvements in jump performance, despite differences in surface stability.

These findings are in line with previous studies comparing the effects of stable and unstable surface training on athletic performance in different sport activities, which have demonstrated similar improvements in strength, power, and balance regardless of surface stability [32,33]. It is likely that the two different warm-up protocols BA and UN could have given significant differences in sensorimotor skills, but no specific tests were performed in this study to evaluate such skills.

Therefore, further studies will be necessary to evaluate these possible differences. However, BA and UN protocols result in a greater neuromuscular response in jumping, using the same number of exercises and total time, compared to the TR one. The partial eta squared of the main effect was large, while the effect size in both protocols resulted to be extremely large. Cohen's d was larger in BA compared to the UN warm-up protocols, with values of −3.220 and −2.318 for the jump height. These results show how both active warm-ups protocols induced better jump performances compared to the traditional warm-up protocol consisting in alternating aerobic and dynamic stretching exercises.

Previous studies reported significant differences in performance between a traditional warm-up versus other active protocols. Chen et al. measured changes in vertical jump height and other physical variables of Taiwanese handball players after a traditional warm-up compared two alternative protocols with core activation or with the use of rubber bands [23], and demonstrated that the ese of experimental warm-up protocols enhance sprint, jump, and throw performances in elite male players compared to a traditional warm-up protocol.

In the study by Dello Iacono et al. the traditional pre-game warm-up turns out to be less effective than a protocol based on small-sided games as final exercise. In particular, the mechanical, physiological, and perceptual responses of handball players were found to be greater by concluding the warm-up procedure with a three-versus-three small-sided game compared to the protocol in which only handball shooting drills were performed [27]. In 2021, Chen et al. studied the acute effects of combining dynamic stretching and vibration foam rolling warm-up on lower-limb muscle performance in female collegiate handball players, comparing two different warm-up protocols versus a generic running warm-up. The dynamic stretching combined with vibration foam rolling exercises was shown to be a better warm-up protocol compared to the traditional one [22]. Based on similar results, Daneshjoo and colleagues suggested replacing the conventional warm-up protocols with a handball warm-up program based on dynamic balance exercises [34].

The results of this investigation also agree with those from Dello Iacono and colleagues, and with those from Thapa and colleagues, who found it more beneficial to conclude the warm-up process with some dynamic exercises like small-sided games [27,35]. Regarding the possible mechanism underlying the apparent better effect of the dynamic warm-up compared to the more static one, Holt and colleagues and Ishak and colleagues observed again that dynamic exercises are better than static ones during the warm-up phase and argued that a dynamic preload stimulus can induce a better post-activation potentiation effect, thereby improving jumping and agility performance in handball [18,36]. Indeed, it has been demonstrated that both isometric and dynamic exercises have the potential to elicit post-activation potentiation, but their effectiveness may vary depending on other factors such as the specific muscle group targeted, the intensity and duration of the exercise, and individual athlete characteristics [37].

Additionally, isometric exercises can create higher levels of muscle tension and neural activation, thus potentially leading to higher potentiation effects. Dynamic exercises, on the other hand, can also induce post-activation potentiation by recruiting many muscle fibers and stimulating the nervous system [38]. Therefore, the choice between isometric and dynamic exercises may depend on other various factors including the athlete's training goals, the sport-specific requirements, and individual preferences.

In handball, it is reasonable that dynamic exercises may be often favored for improving performance in athletes that are subsequently engaged in frequent jumping and direction changes during the game. The adoption of different warm-up procedures, especially in elite athletes, therefore has to be decided based also on individual preferences and personal routines.

The strengths of this study are the ecological setting and the testing of the effect of these warm-up protocols on high-level athletes. The difficulty of working in real-world field settings with high-level athletes has resulted in very few studies conducted and published. Finally, some limitations should be acknowledged. Firstly, the sample size was relatively small. Furthermore, the sample was limited to males, with no females included. Future research with larger and more different samples is needed to validate our findings and to determine the generalizability of the results to other populations. Additionally, only the acute effects of the warm-up protocols were evaluated, but long-term effects on performance were not assessed. Future studies should investigate the sustained effects of different warm-up strategies on jump performance in handball athletes over time.

5. Conclusions

The primary outcome of this investigation is the confirmation that both the BA and UN warm-up routines resulted in notable variations in jump height among elite male

Italian handball players, when compared to the conventional warm-up protocol. The use of dynamic activation exercises represents the best training methodology for the elite handball player during the warm-up routine. Before a match or intense training, optimal activation is achieved by performing dynamic core and lower-limb activation exercises. Hence, both BA and UN warm-up protocols could be used by practitioners for enhancing the neuromuscular properties of the warm-up with respect to traditional warm-up protocols. On the other hand, if a particular neuromuscular activation is not needed (i.e., recovery or tactical sessions), even a TR warm-up can be used. Knowing that greater activation will be obtained by performing the same exercise in an unbalanced condition, practitioners can differentiate warm-up routines based on personal or team needs. To maximize handball players' performance in matches or in training sessions, a specific activation warm-up (BA, UN) is suggested instead of using a TR one. To further help handball players perform at a high level, coaches need to know players' individual acute responses to different warm-up protocols. Finally, standardizing warm-up routines and monitoring daily players' changes allows practitioners and coaches to gather information on players' readiness and recovery level at the beginning of each training session.

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Informed Consent Statement: Written informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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