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Original Article

Impact of different warm-up modalities on the height of countermovement vertical jump and its practical applicability

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Abstract:
The purpose of the study was to find out and compare different warm-up modalities on countermovement vertical jump performance. This study consisted of 12 strength-trained athletes from different kind of sports and also university students of physical education (age: 20 ± 1.1 years; body mass: 82 ± 15.8; body height: 184 ± 8.7). Participants performed 6 warm-up protocols. Protocol 1: Dynamic stretching (DS), protocol 2: Dynamic stretching + ballistic stretching (DS+BAL), Protocol 3: Dynamic stretching + track and field running drills (DS+TFRD), Protocol 4: Dynamic stretching + half-squat jumps (DS+HSJ), Protocol 5: Dynamic stretching + plyometric exercise – drop jumps (DS+DJ), protocol 6: Control testing (CON). Series of independent One–way analysis of variances with repeated measures were used to calculate differences among warm-up protocols and between time intervals. Results show that all warm-up protocols had a positive impact to increase the height of vertical jump compared to CON. The most effective warm-up modality was found DS+HSJ after 3 ($F = 19.603$, $p < 0.01$, ES = 0.641) and 8 ($F = 27.879$, $p < 0.001$, ES = 0.717) minutes of rest interval compared to CON. Significant differences between DS + HSJ in comparison with CON, DS, DS + BAL, DS+TFRD was observed at 1% significance level after 8 minutes of rest. In conclusion, and from practical point of view, if the goal is to increase performance in shorter period of time, each of these warm-up protocols can be useful, but if the goal is to maintain the improved performance for a prolonged period of time then DS+HSJ may be preferable.
Keywords: warm-up; countermovement vertical jump, performance, rest interval

Introduction

At present, attention is paid to various methods of warming-up. It has been demonstrated that static stretching has an adverse and/or depressant effect on performance, respectively. On the other hand, many researchers and practitioners use various methods of dynamic warm-up before sport performance or training session. These warm-up modalities include various sport equipment which makes warm-up more efficient.

For decades static stretching was considered as an essential component of a warm-up and especially among population the most common type of stretching. It comprises movements in which the individual with slow motions stretches certain muscle group and remains in this position for some time (Blahnik, 2013). Examination of static stretching and its impact on the performance has been the subject of interest of several experts. For example, La Torre et al. (2010) examined the acute effects of static stretching on reaction time and balance abilities. The results show that after completing of static stretching significant worsening of reaction time occurred. Currently, in practice and also in the research, various procedures of dynamic warm-up are used. Dynamic warm-up uses controlled movements which are performed in an organized movement patterns in order to increase the range of motion, core body temperature, and also motor unit activation. These exercises are specific for the sport or activity which follows (Vardiman et al., 2010). Influence of dynamic and static stretching on the height of vertical jump and electromyography (EMG) of musculus vastus medialis was examined by Hough et al. (2009). The results showed that jump height significantly decreased after static stretching (4.19 ± 4.47 %; $p < 0.05$) and significantly increased after dynamic stretching (9.44 ± 4.25 %; $p < 0.05$). An interesting study was performed by Haddad et al. (2014) who investigated the impact of static and dynamic warm-up with a delay of 24 hours. They examined changes in explosive power and running speed. Results showed that there were significant differences between static stretching without application of warm-up and dynamic stretching ($F = 9.99$, $p < 0.00$; effect size = 0.40) in explosive power. Similar results were observed in running speed. Authors suggest that application of static stretching can influence the acute performance, while negative effects persist for 24 hours.

Several investigations have demonstrated that application of static stretching had a negative impact on performance or no changes occurred (Winchester et al., 2008; Winke et al., 2010; Perrier et al., 2011; Pinto et al., 2014). On the other hand there are studies where dynamic stretching was performed and positive effects occurred (Chattong et al., 2010; Perrier et al., 2011; Carvalho et al., 2012; Aguilar et al., 2012).

Vanderka et al. (2014) performed an interesting study where they examined influence of different warm-up modalities on vertical jump performance. Their warm-up protocols included isometric exercises,

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plyometric exercises and foam rolling. Results showed that the best improvements occurred after application of dynamic stretching in combination with plyometric exercises (+ 3.1 %, $p < 0.01$) in comparison with dynamic stretching performed independently but greater differences were observed (+ 11.6 %, $p < 0.01$) when compared with the protocol where no warm-up was performed. Authors suggest that incorporating plyometric exercises as a part of dynamic stretching could be a useful method to induce vertical jump performance and thus this way increase efficiency of classic dynamic warm-up methods.

Previous researches stated several factors which relate to the decrease of muscle activity after static stretching. Fowless et al. (2000) indicated that reduction of muscle activity is caused by Golgi apparatus reflex mechanism, feedback mechanisms of mechanoreceptors and nociceptors. Comwell et al. (2001) and Cramer et al. (2004) stated that application of static stretching can cause increase viscoelastic properties of muscle-tendon unit and thus this way to reduce capacity of the muscle to generate power. On the other hand, dynamic warm-up mobilizes energy systems, cardio-vascular system and neuromuscular activation (involvement of several motor units and their frequency of activation) (Isaacs, 1998; Yamaguchi & Ishii, 2005; Faigenbaum, 2012).

In our study different modalities of warm-up were performed which included strength–power exercise and plyometric exercise. These exercises were chosen because it was demonstrated that they are related to postactivation potentiation and their application can cause increase in performance or vice versa fatiguing effect.

Methods

Subjects

Twelve strength trained athletes were chosen to take part in this study. The sample consisted of 3 ice-hockey players, 3 volleyball players (women), 1 karateist (women), 4 soccer players and 1 track and field athlete. Participants´ mean age was 20 ± 1.1 years, body height 184 ± 8.7 centimeters and body mass 82 ± 15.8 kilograms. Athletes were fully informed about the study and potential risks were explained. Participants had at least 5 years´ experiences with regular training arising from their sport specialization and at least 3 years´ experiences with strength training. The local ethics committee approved this study and it was performed in accordance with the Declaration of Helsinki.

Measurements

Familiarization session - Three days before the power and countermovement vertical jump (CMJ) testing session participants were familiarized with each warm-up modality and proper technique how to perform exercises. They also were instructed how to perform countermovement vertical jump properly.

Power and Countermovement Vertical Jump Testing - Testing included warm-up (jogging) during 5 minutes and then dynamic stretching lasting for 7 minutes was performed. Two minutes of rest were included after dynamic stretching followed by CMJ testing. Each participant had 2 attempts and the highest jump height was recorded. Rest interval between attempts was 30 seconds. This testing served for optimization of adjustment of the raised pad for plyometric exercise. It was stated that optimum drop height for plyometric exercise drop jump is approximately equal to maximum jump height reached in countermovement vertical jump with the position of hands on the hips (Bobbert et al., 1986). After completion of CMJ testing 3 minutes of rest followed and participants performed the diagnostic series of half-squat jump exercise. The diagnostic series started with 20 kg Olympic barbell and the burden was gradually increased (+ 10 kg) until maximum average power output was recorded. Subject performed 2 attempts with each weight of a barbell and the highest power output was calculated (Figure 1). Rest interval between attempts was 2 minutes. According to Hamar et al. (1998) this is a reliable procedure to determine maximum average power output. To calculate power output of each participant body mass was added to barbell mass for the calculation of the system mass (Cormie et al., 2007). This power testing served for optimization of barbell load for each participant individually according to results of diagnostic series.

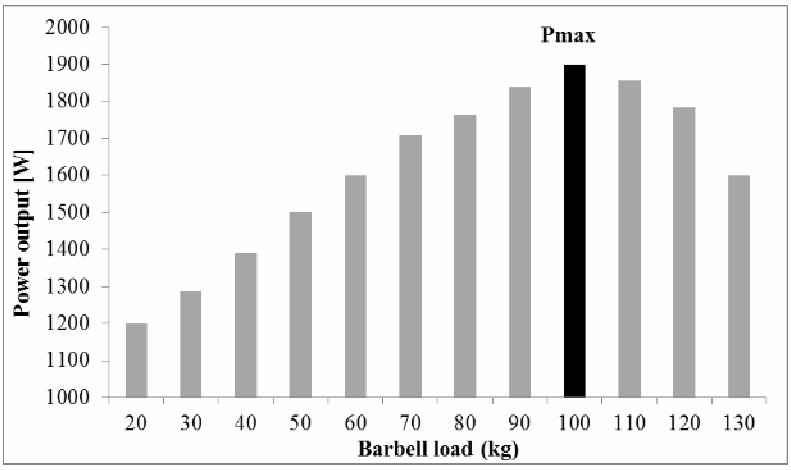

Figure 1 Example of diagnostic series of maximum average power output in ice-hockey player during the half-squat jump exercise

The depth of the half-squat jumps (90° in knee joint) during diagnostic series and warm-up conditioning protocol were controlled by 5 centimeters wide foam cubes. Participants were instructed to perform eccentric phase in a controlled manner and then jump "as high as possible".

Average power output recorded during diagnostic series was 1528.8 ± 226.1 W which corresponded to barbell load 79.1 ± 16.5 kg and average drop height was on the level of 35 cm.

According to the results of this session we constructed additional conditioning protocols. The first conditioning session started within 3 days of the completion of power and CMJ testing.

Measuring equipment

Dynamometric platform Fitro Force Plate (FiTRONIiC Diagnostic and Training Systems, Bratislava, Slovakia) was used for the assessment of the height of countermovement vertical jump. The system consists of strain gauge force plate, electronics, 12-bit AD convertor, interface and software which calculates acceleration, velocity, displacement and power.

For determining maximum average power output Tendo Power Analyzer Weightlifting (TWA) was used (Tendo Sports Machines, Trencin, Slovakia). The system consists of sensor unit, data cable, microcomputer and software which calculate average power, partial average power, peak power (W), average velocity, peak velocity ($m.s^{-1}$), peak force (N) and eccentric average velocity ($m.s^{-1}$) (Guide:tendo Power Analyzer Weightlifting, 2014). According to Garnacho-Castaño et al. (2015) TWA is a reliable device with intra-class correlation coefficient (ICC) 0.922 – 0.988 to measure maximum average power and 0.95 – 0.98 for peak power (2005).

Procedures

A cross-sectional ex–post facto research was used. Our study included 5 warm-up protocols and 1 control protocol. Participants were divided into 6 subgroups (each subgroup comprised two subjects) and completed 6 conditioning sessions with a 3-day-long interval between sessions. Each subgroup performed different warm-up modality and the order of subgroups was rotated in the next conditioning session until all participants performed each of the warm-up protocols. The study duration was nearly four weeks, including power and vertical jump testing session. Using this procedure we tried to avoid adaptation to training or other physical activity and the impact of the order on the jump height.

Warm-up protocols consisted of:
1. Dynamic stretching (DS),
2. DS + ballistic stretching (BAL),
3. DS + track and field – running drills (TFRD),
4. DS + half-squat jumps (HSJ),
5. DS + plyometric exercise – drop jumps (DJ),
6. Control protocol (CON).

Dynamic stretching included 5 exercises focused on the major muscle groups (mm. glutei, m. biceps femoris, m. semitendinosus, m. semimembranosus, m. quadriceps femoris, m. gastrocnemius). The exercises were performed in the following order: plantar flexors, hip extensors, hamstrings, hip flexors and quadriceps femoris (Yamaguchi et al., 2005; Hough et al., 2009). Exercises were performed 5 times slowly and 10 times quicker but without bouncing on both legs. Rest interval between exercises was 15-seconds. The duration of the dynamic stretching was approximately 7 minutes in each protocol except for control protocol. Ballistic stretching consisted of 4 exercises on the major muscle groups. Exercises consisted of: forward lunge, supine knee flex, standing quadriceps stretch, sitting toe touch (Jaggers et al., 2008). Participants performed each exercise by bouncing rapidly for 30 seconds on both legs. 15-seconds rest interval between exercises was included. Track and field running drills comprised 5 exercises and participants performed 2 series of 5 exercises along the distance of 10 meters (totally 100 meters) and 1 minute of rest was added between sets. Exercises consisted of: low knees, middle knees, high knees, double leg alternating high knee butt-kicks and A-skips. In the HSJ protocol subjects performed 2 series of 4 repetitions of half-squat jumps with 3 minutes of rest interval between sets. Plyometric exercise consisted of 2 series and 6 repetitions of drop jumps with 2 minutes of rest interval between sets. The duration of these additional protocols was 5 minutes. This way we were trying to ensure internal validity of experiment stimuli in the terms of the time duration of each warm-up protocol (total duration of warm-up modalities was 12 ± 1 minutes). Control protocol consisted of jogging lasting for 5 minutes followed by 3 minutes of rest and then participants performed CMJ testing.

During the drop jumps subjects were instructed to "reverse the downward velocity into the upward one as soon as possible after landing" according to the study by Bobbert et al. (1987). The first post-testing of jump height was performed after 3 minutes of rest interval and the second one after 8 minutes. Every participant executed 2 attempts and the highest jump height was recorded. Figure 2 shows schematic illustration of warm-up and control protocols.

Subjects who were part of the study were acquainted with the fact that they have to avoid any training load focused on maximum strength and power 48 hours prior to the testing and also during the whole period of the study. The ingestion of ethyl alcohol was prohibited for 24 hours before every testing and caffeine for 3 hours before every conditioning protocol.

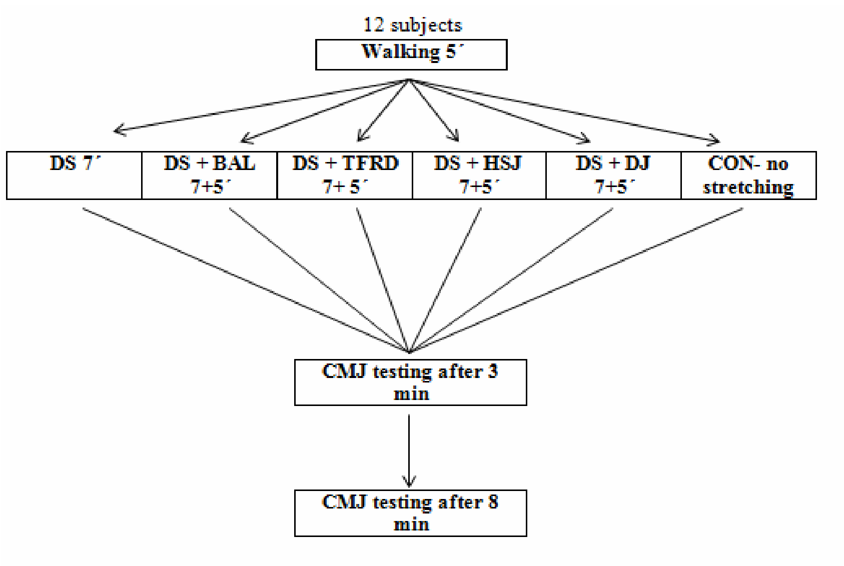

Figure 2 Schematic illustration and procedure of different warm-up modalities

Statistical analyses
Series of independent One – way ANOVA with repeated measures were performed to evaluate significant differences between warm-up modalities and time intervals. Holm´s Bonferroni post hoc test was used to identify where the significant differences among protocols occurred. Effect size (Partial Eta-squared) was used to determine practical significance. IBM SPSS version 20 to evaluate descriptive statistic and statistical methods was used.

Results
Significant difference was observed for warm-up conditions (F = 17.034, p < 0.001, ES = 0.826, power = 1.000), while no significant differences were observed for time (F = 0.207, p = 0.955, ES = 0.054, power = 0.087).
Post hoc test revealed that there was significant difference after 3 minutes of rest interval between DS and CON (F = 7.173, p = 0.021, ES = 0.39, confidence interval = 0.673 to 6.877 cm, power = 0.684), DS + BAL and CON (F = 7.658, p = 0.018, ES = 0.410, confidence interval = 0.911 to 7.989 cm, power = 0.712), DS + TFRD and CON (F = 6.510, p = 0.027, ES = 0.372, confidence interval = 0.588 to 7.978 cm, power = 0.643), DS + HSJ and CON (F = 19.603, p = 0.001, ES = 0.641, confidence interval = 3.202 to 9.532 cm, power = 0.980), DS + DJ and CON (F = 21.445, p = 0.001, ES = 0.661, confidence interval = 3.183 to 8.950 cm, power = 0.987).

Table 1 Average values of countermovement vertical jump after performing different modalities of warm-up protocols

WARM-UP	POST-COND after 3 min (Average ± SD) (cm)	POST-COND after 8 min (Average ± SD) (cm)	DF (Average) (cm)
DS	36.1 ± 3.0	35.5 ± 3.0	-0.6
DS + BAL	36.8 ± 3.1	35.5 ± 2.6	-1.3
DS + TFRD	36.6 ± 2.8	35.2 ± 1.4	-1.4
DS + HSJ	38.7 ± 3.7	39.3 ± 3.2	+0.6
DS + DJ	38.4 ± 2.9	37.4 ± 1.8	-1.0
CON	32.3 ± 3.9	32.5 ± 3.5	+0.2

Note. POST-COND = Post-conditioning; SD = Standard deviation; DF = Difference; DS = Dynamic stretching, DS + BAL, + TFRD, + HSJ, + DJ = Dynamic stretching with additional activity consisting of ballistic stretching, track and field running drills, half-squat jumps, drop jumps; CON = Control protocol

Marginally significant differences between warm-up protocols occurred when DS and DS + HSJ (F = 4.292, p = 0.063, ES = 0.281, confidence interval = -0.162 to 5.345, power = 0.472) were compared after 3 minutes of rest.

When we compared differences after 8 minutes of rest, significant differences were observed between DS and CON (F = 6.631, p = 0.026, ES = 0.376, confidence interval = 0.438 to 5.595 cm, power = 0.650), marginal significance was observed between DS + BAL and CON (F = 4.461, p = 0.058, ES = 0.289, confidence interval = -0.129 to 6.245 cm, power = 0.487), DS + TFRD and CON (F = 6.470, p = 0.027, ES = 0.370, confidence interval = 0.373 to 5.161 cm, power = 0.640), DS + HSJ and CON (F = 27.879, p = 0.000, ES = 0.717, confidence interval = 4.014 to 9.753 cm, power = 0.998) DS + DJ and CON (F = 22.113, p = 0.001, ES = 0.668, confidence interval = 2.646 to 7.304 cm, power = 0.989).

Significant differences between dynamic warm-up protocols after 8 minutes of rest were observed when we compared DS + HSJ and DS (F = 10.026, p = 0.009, ES = 0.477, confidence interval = 1.179 to 6.554 cm, power = 0.821), DS + HSJ and DS + BAL (F = 10.235, p = 0.008, ES = 0.482, confidence interval = 1.194 to 6.456 cm, power = 0.829), DS + HSJ and DS + TFRD (F = 12.289, p = 0.005, ES = 0.528, confidence interval = 1.532 to 6.701 cm, power = 0.890). There was no significant difference between HSJ protocol when compared with DJ protocol (F = 2.221, p = 0.164, ES = 0.168, confidence interval = -0.910 to 4.727 cm, power = 0.275). Interestingly, no significant differences were recorded when DS + DJ were compared with DS, DS + BAL, DS + TFRD.

Table 1 shows values of countermovement vertical jump performance after completion of various warm-up modalities.

Discussion

The main aim was to find out the impact of different warm-up modalities on height of countermovement vertical jump. The main finding of the study was that each of the dynamic warm-ups had a positive impact on the height of vertical jump after 3 minutes of rest when compared to control protocol. When we compared dynamic warm-up protocols among each other there was marginal significance only in the case of DS + HSJ compared to DS. These findings are in line with previous studies (Turki et al., 2011; Carvalho et al., 2012) where it was reported that dynamic stretching alone is sufficient to provide the potentiation of vertical jump performance when compared to control protocol with no additional activity. In the study by Turki et al. (2011) they used dynamic stretching lasting 10 minutes plus isometric, concentric-only, eccentric-only, heavy strength and plyometric exercises. Results showed that dynamic stretching itself was sufficient to provide the potentiation of vertical jump and additional activity might promote fatigue. These results are comparable to our findings where all protocols had a positive impact on jump height compared to control protocol, but when we compared protocols with additional activity marginal significance was observed only between DS + HSJ and DS. We assume that 3 minutes of rest interval could not allow for full resynthesizing of phosphocreatine and thus no significant changes between dynamic warm-ups with additional activity occurred because of increased fatigue. Results showed that there were comparable values for DS, DS + BAL and DS + TFRD. Few studies have examined the effects of ballistic stretching on maximum jump height (Unick et al., 2005; Jaggers et al., 2008) and no significant difference in maximum jump height was observed. In our study BAL was a part of dynamic stretching because of injury risk when it was performed independently. In this case we suppose that ballistic stretching had no effect on vertical jump height and explanation can be twofold: the first one is that dynamic stretching which was performed before BAL might be sufficient and the influence of BAL failed to have a significant impact on vertical jump height. The second one may be based on the association of the neutral effect with the recovery of the motor neuron excitability caused by the Hoffmann reflex (Unick et al., 2005). Another type of warm-up protocol included DS + TFRD exercises which are commonly used by athletes of various sports and mainly by track and field athletes. Similar results were observed in comparison with other protocols. We assume that performing DS plus running drills could have caused fatiguing effect and their design did not have to sufficiently stimulate muscle fibers of type II and the reached level of jump height maintained comparable values to other protocols except for DS + HSJ warm-up.

The study included strength-power and plyometric exercises. These types of exercises are mainly associated with postactivation potentiation. There are several studies where vertical jump performance was enhanced after intervention of resistance exercise (Smilios et al., 2005; Moir et al., 2011; Crewther et al., 2011; Hirayama, 2014) and plyometric exercises (Chen et al., 2013; Tobin & Delahunt, 2014). We can assume that potentiating effect occurred after intervention of 2 set and 4 repetitions of half-squat jumps, but exact mechanism of PAP is still unknown. Scientific community discusses about enhanced excitability of the motoneurone pool (Gulich & Schmidtbleicher, 1996; Young et al., 1998) or myosin light chain functioning (Sweeney et al., 1993). Possible changes in pennation angle are also frequently mentioned (Tillin & Bishop, 2009).

Even more significant differences were observed after 8 minutes of rest after completion DS + HSJ warm-up protocol. These results are in agreement with Wilson et al. (2013) who constructed meta-analysis of 32 studies dealing with PAP. Results of their study indicate that incorporating 3 – 7 minutes of rest after intervention of resistance exercise is adequate for the occurrence of PAP effect. These findings are similar to other ones (Jo et al., 2010; Mitchel & Sale, 2011; Seitz et al., 2014). In the study by Wilson et al. (2013) there is also a mention about optimum volume and external load which is recommended to achieve positive PAP effect (e.g. 2 or more sets per exercise, external load approximately 60 – 80 % 1RM) which is consistent with our experimental stimuli. Height of vertical jump did not increase after performing DS, DS + BAL and DS + TFRD after 8 minutes of rest but maintained a stable level with minimum decrease. It should be noted that in our protocol active rest was applied (slow jogging) between CMJ attempts. According to Wilmore & Costill (2004) who stated that if prolonged passive recovery is included between attempts, exercises or sets heart rate frequency is decreased through parasympathetic nervous system and also glanderous and periosteal secretion is increased and thus this way relaxation processes begin. On the basis of this argument we assume that active rest applied in our study could not allow for relaxation processes arise in such an extent.

Interesting but unexpected results were observed after performing DS + DJ. Although the values of a vertical jump were the highest with DS + HSJ among all protocols but in this case there were no significant differences compared to other DSs with additional activity. In our study participants performed 2 sets and 6 drop jumps which was similar design like in the study by Chen et al. (2013) where subjects performed 2 sets and 5 drop jumps and significant changes were greater at post 6 minutes of rest ($p = 0.004$) than at post 2 ($p = 0.008$) and 12 ($p = 0.018$) minutes. According to Crewther et al. (2011) who mentioned in their study that potentiating effects of squats may exhibit some degree of movement specificity, being greater for those exercises with similar movement patterns. There logically exist also different ways how to perform drop jump so that it be more specific for subsequent physical activity. Young et al. (1995) by Bobbert et al. (1986) monitored handball players who used different DJ techniques: bounce technique (ground contact time < 200 ms) and counter technique (ground contact time >260 ms). Results showed that counter technique produced similar jump height as countermovement jump. Subjects using the bounce technique produced greater maximum power about the knee, and greater minimum hip, knee and ankle angles during the take off. Bobbert et al. (1987) also indicate that during counter technique is a larger downward movement upon landing and it is more specific to countermovement vertical jump. These differences between the two types of drop jump techniques are also stated by Zatsiorsky & Kraemer (2006). In our study subjects performed bounce technique where they were instructed to "reverse the downward velocity into the upward one as soon as possible after landing" which corresponds to bounce technique. We assume that movement specificity could cause different effects on subsequent activity which do not correspond with countermovement vertical jump.

In summary, all warm-up protocols except for the control one with no dynamic stretching plus additional activity caused significant improvement after 3 and 8 minutes of rest compared to control protocol. Combination of DS + HSJ as the warm-up modality in our study proved to be most effective. One of the subjects from our study was distance runner and in his case there were no improvements in jump height when we compared DS + HSJ and other DS + additional activity after 3 and 8 minutes of rest.

Conclusions

We realize that limitation of the study consists in inadequate monitoring of other parameters such as peak power output, force during the take-off, but the aim of this study was to show the impact of different modalities of dynamic warm-up mainly for practitioners. The test which was chosen is simple, but frequently used in the practice.

In conclusion, and from practical point of view, if the goal is to enhance height of vertical jump in a shorter period of time, than all warm-up modalities presented in our study can be used. If the goal is to maintain or increase height of vertical jump for a prolonged period of time, than dynamic stretching plus additional activity e.g. in the form half-squat jumps can be useful. In any case, training background of participants should not be forgotten when strength-power loading is used and also individualization of loading, as one of the most essential factors, which affects performance and its extent, should be taken into account.

Conflict of interests

Authors declare that there is no conflict of interests connected with other studies or authors.

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