

ACUTE EFFECTS OF A RESISTED DYNAMIC WARM-UP PROTOCOL ON JUMPING PERFORMANCE

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ABSTRACT: This study aimed to investigate the kinematic and kinetic changes when resistance is applied in horizontal and vertical directions, produced by using different percentages of body weight, caused by jumping movements during a dynamic warm-up. The group of subjects consisted of 35 voluntary male athletes (19 basketball and 16 volleyball players; age: 23.4 ± 1.4 years, training experience: 9.6 ± 2.7 years; height: 177.2 ± 5.7 cm, body weight: 69.9 ± 6.9 kg) studying Physical Education, who had a jump training background and who were training for 2 hours, on 4 days in a week. A dynamic warm-up protocol containing seven specific resistance movements with specific resistance corresponding to different percentages of body weight (2%, 4%, 6%, 8%, 10%) was applied randomly on non consecutive days. Effects of different warm-up protocols were assessed by pre-/post- exercise changes in jump height in the countermovement jump (CMJ) and the squat jump (SJ) measured using a force platform and changes in hip and knee joint angles at the end of the eccentric phase measured using a video camera. A significant increase in jump height was observed in the dynamic resistance warm-up conducted with different percentages of body weight ($p < 0.05$). On the other hand, no significant difference in different percentages of body weight states was observed ($p > 0.05$). In jump movements before and after the warm-up, while no significant difference between the vertical ground reaction forces applied by athletes was observed ($p > 0.05$), in some cases of resistance, a significant reduction was observed in hip and knee joint angles ($p < 0.05$). The dynamic resistance warm-up method was found to cause changes in the kinematics of jumping movements, as well as an increase in jump height values. As a result, dynamic warm-up exercises could be applicable in cases of resistance corresponding to 6-10% of body weight applied in horizontal and vertical directions in order to increase the jump performance acutely.

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INTRODUCTION

In particular, the warm-up exercises conducted prior to activities that require high power output are believed to play an important role in determining performance, preventing injuries, and reducing muscle pain after exercise. The warm-up period usually starts at a moderate level and increases in intensity to aerobic runs. Following this run, athletes then do static stretching exercises. However, recent studies have shown that static stretching prior to a competition or training inhibited performance by reducing speed, power and strength [1,2,3,4,5].

Knowledge of the negative effects of static stretching prior to athletic performance has caused sport scientists, coaches, and athletes interested in this field to search for alternative methods. One of these alternatives is the implementation of dynamic warm-up exercises. This type of exercise actually forms the basis of sports movements used in training or competition. Prior studies in this area proposed that voluntary contractions from a moderate level, such as a dynamic warm-up, to a high-intensity level increase power generation and performance by activating nerve-muscle functions [6,7,

8,9,10,11]. This is called post-activation potentiation (PAP), which is a temporary increase in the ability of muscles to contract after previous contraction sessions [12]. One of the main mechanisms that makes PAP more effective is the interaction between actin-myosin resulting from myosin light chain phosphorylation, while another mechanism is neural excitability [12,13].

Dynamic warm-up includes load resistance exercises, plyometric movements, or maximum voluntary contractions (MVC). Its forms generally include walking, high knee pulls, skipping, carioca, various jumping exercises and gradually increasing acceleration movements and their combinations. In load resistance exercises using weighted vests, it was observed that dynamic warm-up exercises cause an increase in jump performance with the addition of weights that are 2–15% of the body weight when resistance is vertically created [9,11]. In these studies, warm-up exercises were performed by placing additional weights into small pockets on the participants. Weighted vests cause only vertical resistance to the athletes' bodies. The acute effects of dynamic resistance warm-up, by creating resistance on

athletes' bodies in front-rear, left-right, and up-down directions, on performance, are not yet known. In addition, the number of studies is simply insufficient regarding the patterns, duration, repetitions, and intensity of movements used in the dynamic warm-up resistance exercises. The aim of this study was to investigate the acute effects of dynamic warm-up protocols applied by using different percentages of body weight in the countermovement jump (CMJ) and squat jump (SJ).

MATERIALS AND METHODS

Experimental approach to the problem. A within-subject, balanced, randomized repeated-measures design was used to test the experimental hypotheses. This study was established in five experimental sessions. The participants performed a dynamic warm-up with resistance corresponding to different percentages of their body weights in each session (2%, 4%, 6%, 8%, and 10%). Jump tests, which consist of SJs and CMJs without arm action, were applied to the participants immediately before and after each experimental session, and the kinematic and kinetic changes caused by jumping were examined. Protocols were applied with 48-hour intervals.

Subjects

The group of subjects consisted of 35 voluntary male athletes (19 basketball and 16 volleyball players; age: 23.4 ± 1.4 years, training experience: 9.6 ± 2.7 years; height: 177.2 ± 5.7 cm, body weight: 69.9 ± 6.9 kg) studying Physical Education, with a jump training background, who were training for 2 hours, on 4 days in a week. Protocols were applied at the middle of the competition session.

All subjects reported no significant history of recent musculoskeletal injury. Before participating in the study, subjects were informed of the potential risks and benefits, and provided written informed consent to participate in accordance with the policies and procedures of Sakarya University's Human Research Ethics Committee for the use of human subjects in research. The subjects were requested to refrain from caffeine intake on each testing day and to avoid food consumption in the two hours before testing.

Procedures

Prior to data collection, introductory and trial sessions about resistant dynamic warm-up were held two days before the first test for each participant included in this study. These introduction and trial sessions were conducted in order to eliminate the effect of learned knowledge. All of the resistant dynamic warm-ups and tests were administered by the same instructor.

Resistant dynamic warm-up protocol

All of the resistant dynamic warm-up applications were administered by a cable crossover (Body-Solid, GDCC200, IL 60130 USA), an instrument used in resistance exercises. The resistance states were provided in front-rear, left-right, and up-down directions by fixing the two ends of the cable with free weights in this device to the weight-



FIG. 1. INSTRUMENT USED IN RESISTANCE EXERCISES

ed vests (1-VestTM, OR, Portland) with hooks (Figure 1). The participants performed seven warm-up exercises with the resistance corresponding to different percentages of their body weights (2%, 4%, 6%, 8%, 10%). After light tempo runs (1.5 min), the participants ran with a light back and forth running tempo at a 3-meter distance (1.5 min). Then followed by right and left side diagonal lunge which performed by step forward at a 45-degree angle with your knee lined up with your toes at a 2-meter distance (1 min). They performed a V-step on a step platform (1 min). They continued the movements on a step platform without interruption by jumping a couple of feet up, and back down in a similar way (1 min). They continued the warm-up protocol by performing left and right in-line lunge movements (1 min). Finally, they jumped laterally right and left sides at a 45-degree angle (1 min). All resistance dynamic warm-up exercises with one repetition continued for 8.5 min.

Kinematic data

The CMJ and SJ movements the participants performed before and after resistant dynamic warm-up were digitized through passive markers placed on the participant's right side (shoulder, hip, knee, and ankle) by means of one video camera (Canon, MD101) with a 50 frame/s recording speed. The hip and knee joint angles were calculated from the data obtained using a two-dimensional position. The lowest hip and knee joint angle values were compared in each jump movement before and after the warm-up.

Jump height and kinetic data

SJ and then CMJ, without arm action, jump tests were performed in this study. The vertical reaction force values applied to the ground

during the jumping movements of the participants before and after warm-up were recorded on a force platform (Kistler, 9290AD, Quattro Jump model) with a 500 Hz data collection rate. The jump height and the highest relative force applied to the ground (force/body weight) values were compared in each jump movement before and after the warm-up by using the obtained data. CMJ and SJ were applied three times, and the best value was used for analysis.

Statistical analyses

The descriptive statistics (mean ± standard deviation) of variables, such as age, height, body weight, CMJ and SJ test were calculated. The Kolmogorov-Smirnov normality test was used to check the normality of the continuous variables. The repeated measures one-way analysis of variance (ANOVA) (for pairwise comparison the LSD test was used) was used in order to determine the differences in warm-up protocols and the effect of each warm-up protocol, respectively. In addition, the paired sample t test was used to determine the significance of differences between the variables obtained before and after each warm-up performed with different percentages of body weight. The level of significance was accepted as p < 0.05. Analyses were performed using statistical software (IBM SPSS Statistics 20, SPSS inc., an IBM Co., Somers, NY).

RESULTS

The jump height values of the participants involved in this study before (pre-WU) and after warm-up (post-WU) are shown in Table 1. It can be seen that the jump height values were significantly increased

after resistant dynamic warm-up protocols applied with all percentages of body weight (p < 0.05). The highest performance increase was observed after resistant dynamic warm-up carried out with the addition of 10% body weight for both CMJ and SJ. While the highest performance increase was observed after resistant dynamic warm-up carried out with 10% body weight for SJ (9.79%), the lowest difference was observed after resistant dynamic warm-up with 6% of body weight for CMJ (4.17%). There was a statistically significant difference between 6% BW and 10% BW protocols in terms of the CMJ jump height. The difference between 8% BW and 10% BW protocols was also significant. But there was no significant difference in the percentage increase of jump height between 5 protocols for SJ.

The ground reaction forces in the vertical direction applied in CMJ and SJ jump movements were compared between before and after resistant dynamic warm-up and there was no significant difference observed, except for the 6% relative force increase (p < 0.05) obtained for the SJ after the warm-up carried out with 8% of body weight. When the effect of resistant dynamic warm-up on the ground reaction forces (GRF) was compared according to different percentages of body weight, while differences between different percentages of body weight were observed for SJ movements, there was no change observed for CMJ movements (Table 2).

The hip and knee joint angle values observed in the CMJ and SJ movements before and after resistant dynamic warm-up belonging to the participants are shown in Table 3 and Table 4. In CMJ and SJ movements after resistant dynamic warm-up, a general decreasing trend was observed in the hip and knee joint angles of the participants

TABLE 1. COMPARISON OF THE JUMP HEIGHTS BETWEEN BEFORE WARM-UP (Pre_WU) AND AFTER WARM-UP (Post_WU) FOR DIFFERENT PERCENTAGES OF BODY WEIGHT

	Pre_WU	Post_WU	Difference	¹ p
Countermovement Jump (cm)				
%2 of BW	33.3±0.1	35.5±0.1	+ 6.61	<0.001
%4 of BW	34.6±0.5	36.3±0.5	+ 4.91	<0.019
%6 of BW	33.6±0.5	35.0±0.6	+ 4.17	<0.035
%8 of BW	34.3±0.4	36.1±0.5	+ 5.25	<0.001
%10 of BW	33.6±0.5	36.7±0.6	+ 9.23 ^{a,b}	<0.001
² p			0.036	
Squat Jump (cm)				
%2 of BW	32.6±0.4	35.6±0.4	+ 9.20	<0.001
%4 of BW	33.5±0.5	35.6±0.5	+ 6.27	<0.006
%6 of BW	32.2±0.5	34.5±0.5	+ 7.14	<0.007
%8 of BW	32.8±0.4	35.5±0.4	+ 8.23	<0.001
%10 of BW	32.7±0.5	35.9±0.5	+ 9.79	<0.001
² p			0.560	

Note: Data were shown as mean ± standard deviation.
¹p: Results of the comparison between Pre and Post test.
²p: Results of the comparison among five approaches (percentages of body weight).
 According to pairwise comparisons of repeated measures ANOVA;
^a: There was statistically significant difference from %8, ^b: There was statistically significant difference from %6.

TABLE 2. COMPARISON OF THE MAXIMUM GRF VALUES BETWEEN BEFORE WARM-UP (Pre_WU) AND AFTER WARM-UP (Post_WU) FOR DIFFERENT PERCENTAGES OF BODY WEIGHT

	Pre_WU	Post_WU	Difference	¹ p
Countermovement Jump (BW)				
%2 of BW	2.95±0.46	2.95±0.51	0.00	1.000
%4 of BW	2.90±0.52	2.84±0.47	- 2.12	0.623
%6 of BW	2.92±0.44	2.93±0.55	+ 0.28	0.923
%8 of BW	2.88±0.52	2.82±0.45	- 2.17	0.389
%10 of BW	2.87±0.43	2.72±0.39	- 5.28	0.071
² p			0.574	
Squat Jump (BW)				
%2 of BW	2.51±0.33	2.62±0.44	+ 4.35	0.119
%4 of BW	2.66±0.37	2.54±0.31	- 4.71 ^a	0.074
%6 of BW	2.51±0.31 ^b	2.64±0.40	+ 5.23 ^b	0.143
%8 of BW	2.46±0.37	2.60±0.31	+ 5.60 ^b	<0.039
%10 of BW	2.56±0.36	2.47±0.32	- 3.54 ^d	0.186
² p			0.021	

Note: Data were shown as mean ± standard deviation.
¹p: Results of the comparison between Pre and Post test.
²p: Results of the comparison among five approaches (percentages of body weight).
 According to pairwise comparisons of repeated measures ANOVA;
^a: There was statistically significant difference from %2, ^b: There was statistically significant difference from %4, ^c: There was statistically significant difference from %8

except for some body weight percentages. While the greatest decrease in the hip joint was observed after resistant dynamic warm-up carried out with 10% body weight for the SJ (10.1%), the lowest decrease was observed after resistant dynamic warm-up carried out with 6% body weight for the SJ (1.7%). There was no significant difference observed in the hip joint angles of the participants after resistant dynamic warm-up for CMJ and SJ movements. There was also no significant difference observed when the effects on the angular position values produced in the hip and knee joint angles of the CMJ movement were compared to the different percentages of body weight. In contrast, for the SJ movement, the differences between the 2-6% body weight in the hip joint angles and the 6-10% body weight in the knee joint angles were significant ($p < 0.05$).

DISCUSSION

This study was conducted in order to investigate the acute effects of dynamic warm-up protocols applied by using different percentages of body weight in the CMJ and SJ. The most striking result of this study is that resistant dynamic warm-up causes an increase in jump height values obtained in CMJ and SJ movements that require a high power output. These overall results support the findings of previous studies demonstrating that dynamic warm-ups increase power and speed performance [6,7,11].

In the study conducted by Thompsen [11] on 16 female athletes using weighted vests, a dynamic warm-up was performed for 10 min on the subject with a resistance corresponding to 10% of body weight. It was observed that the resistant dynamic warm-up caused 5.3% and 5.4% improvement in long jump and vertical jump performance,

respectively. In another study conducted by Burkett [6], the effect of four different warm-up protocols on jump performance was investigated in college football players. One protocol was the dynamic warm-up protocol with a resistance corresponding to 10% of body weight. After this protocol, a 3.3% increase was observed in vertical jump performance. In the study conducted by Faigenbaum [7] on high school female athletes, the effects of a dynamic warm-up protocol on fitness performance with and without a weighted vest were investigated. Investigation protocols included resistance corresponding to 2% and 6% of body weight that was similarly placed to a weighted vest. As a result of their study, it was found that a resistance corresponding to 2% of body weight increased vertical jump performance by 10.1%, and a resistance corresponding to 6% of body weight increased vertical jump performance by 13.5% and long jump performance by 12.5%. In the study conducted by Tahayori [9] and performed with weighted vests, there was a significant increase observed in men after resistant dynamic warm-up with 15% of body weight, while there was no significant increase observed in women.

Although more research is required in this field, it is believed that the exercises applied in resistant dynamic warm-up have an effect on the increase in the production of explosive power by increasing neuromuscular function. This phenomenon is known as “post activation potentiation” (PAP) [12]. Although the mechanisms that activate PAP are still being examined, the existing theories postulate that a certain chemical temporarily aids the contractile properties of muscle tissue, and neuromuscular and mechanical changes [13,12]. In addition to the mechanism related to potentiation, previous studies have suggested that the properties of individuals such as training

TABLE 3. COMPARISON OF THE MINIMUM HIP (HA) JOINT ANGLE VALUES BETWEEN BEFORE WARM-UP (Pre_WU) AND AFTER WARM-UP (Post_WU) FOR DIFFERENT PERCENTAGES OF BODY WEIGHT

	HA Pre_WU	HA Post_WU	Difference	¹ p
Countermovement Jump (degree)				
%2 of BW	117.8 ± 13.5	113.0 ± 13.8	- 4.1	<0.038
%4 of BW	114.4 ± 16.0	110.3 ± 15.4	- 3.6	0.234
%6 of BW	116.2 ± 16.9	105.8 ± 20.3	- 9.0	<0.012
%8 of BW	113.5 ± 13.0	105.5 ± 18.0	- 7.0	<0.023
%10 of BW	114.5 ± 13.8	111.1 ± 17.9	- 3.0	0.304
² p			0.508	
Squat Jump (degree)				
%2 of BW	110.8 ± 14.1	102.6 ± 13.8	- 7.4	<0.017
%4 of BW	110.9 ± 15.0	102.5 ± 15.4	- 7.6	<0.028
%6 of BW	109.0 ± 17.0	106.8 ± 14.7	- 2.0	0.466
%8 of BW	103.1 ± 16.5	101.3 ± 19.8	- 1.7	0.602
%10 of BW	109.6 ± 13.0	98.5 ± 18.7	- 10.1	<0.011
² p			0.175	

Note: Data were shown as mean ± standard deviation.
¹p: Results of the comparison between Pre and Post test.
²p: Results of the comparison among five approaches (percentages of body weight).

TABLE 4. COMPARISON OF THE MINIMUM KNEE (KA) JOINT ANGLE VALUES BETWEEN BEFORE WARM-UP (Pre_WU) AND AFTER WARM-UP (Post_WU) FOR DIFFERENT PERCENTAGES OF BODY WEIGHT

	KA Pre_WU	KA Post_WU	Difference	¹ p
Countermovement Jump (degree)				
%2 of BW	109.0 ± 10.2	110.2 ± 8.2	+1.1	0.485
%4 of BW	107.3 ± 10.6	106.7 ± 9.9	- 0.6	0.791
%6 of BW	109.6 ± 8.6	106.8 ± 11.1	- 2.6	0.188
%8 of BW	106.8 ± 7.5	105.5 ± 9.3	- 1.2	0.552
%10 of BW	110.1 ± 7.9	109.3 ± 12.1	- 0.7	0.716
² p			0.773	
Squat Jump (degree)				
%2 of BW	106.7 ± 6.84	101.7 ± 9.66	- 4.9	<0.011
%4 of BW	106.7 ± 7.0	101.8 ± 10.2	- 4.6	0.386
%6 of BW	106.8 ± 7.5	104.8 ± 9.3	- 1.9	<0.045
%8 of BW	103.4 ± 7.3	107.6 ± 7.1	+ 4.1	0.657
%10 of BW	105.0 ± 6.5	104.0 ± 11.4	- 1.0	0.280
² p			0.052	

Note: Data were shown as mean ± standard deviation.
¹p: Results of the comparison between Pre and Post test.
²p: Results of the comparison among five approaches (percentages of body weight).

status or fibre-type distribution may determine the ability to reveal PAP [4,12]. Furthermore, in some studies, it was observed that the fast-twitch dominant muscles show a higher level of potentiation than slow-twitch dominant muscles, and are particularly effective in activities such as sprinting [4]. Young [14] used 1 set of 5 RM squat loads within the warm-up in their study, and they observed a 2.8% increase in jump height. Gullich and Schidtbleicher [15] reported a 3.3% increase in vertical jump height as a result of the high intensity MVC prior to the test. Similarly 2.4% improvement in jump performance was observed by Gourgoulis [16] after half-squats of gradually increasing intensity. In the aforementioned studies, it was proposed that the dynamic loading of contractions performed prior to the activities that require high power, such as the vertical jump, stimulates the central nervous system and these applications allow explosive effort to be exerted.

It can be concluded that the dynamic warm-up exercises increase the excitability of the fast-twitch muscles with the resistances corresponding to 6% and 10% of body weight used in this study, and therefore, prepared them to play an important role during activities such as the CMJ and SJ.

Chattong [17] performed a dynamic warm-up with additional weights corresponding to 0%, 5%, 10%, 15% and 20% of body weight by using a weighted vest on a group of 20 resistance trained men mean aged 22 years. They did not find any significant difference between dynamic warm-up protocols conducted with the additional weights corresponding to different percentages of body weight. Another study in this field was conducted by Reiman [18] on a group of 16 high school male football players, aged 14-18 years. In their study, the effect of a dynamic warm-up conducted with and without a weighted vest on lower extremity power performance was investigated. In that study, dynamic warm-ups were performed with an additional weight corresponding to 5% of body weight. There was no significant difference in the dynamic warm-up protocol conducted without a weighted vest.

In this study there were no statistically significant changes in the GRF between pre-WU and post-WU values. Therefore, the GRF values of this study do not support the idea that resistance exercise increases muscle output after the defined dynamic warm-up protocol presented. In addition to the similarities of GRF values, there is evidence to support that using resistance dynamic warm-up exercises may affect some kinematic parameters of the jumps. The key point of this study is that peak values of knee and hip joint angles revealed an insignificant decrease in the post-exercise jumps. This insignificant

increase in the range of motion of knee and hip joints could be the cause of the increase in jump height. Although time and velocity parameters were not analyzed in our study, they may have the potential to cause an increase in jump height. It was observed that using weighted vests changed the style and the timing of the jump, rather than the peak values of joint moments [9]. A decrease in the duration of pre-take off and an insignificant increase in joint velocity could be the cause of the increase in jump height [9]. However, it is not clearly understood how exercising with a weighted vest increases jump height. Possible mechanisms include changes in angular displacement or the velocity of the joints, as well as a change in the timing and/or coordination of the movement, thus optimizing the movement. Therefore, it can be proposed that dynamic warm-up with resistance exercise temporarily affects some specific characteristics of jumping.

CONCLUSIONS

The data obtained from this study demonstrated that resistant dynamic warm-up acutely increases jump performance. As a result, we propose that dynamic warm-up using a resistance corresponding to 6-10% of body weight may cause PAP, and therefore may acutely increase jump performance. In particular, the application of PAP caused by resistant dynamic warm-up exercises seems to be a potential area for further research in order to improve athletic performance that requires high power output.

The additional weights corresponding to the various percentages of body weight were fixed to the participants' weighted vests with hooks by means of cables. The application of this warm-up method, applied in controlled laboratory conditions, seems to be difficult, particularly prior to implementation with high competition stress. On the other hand, dynamic warm-up exercises performed by athletes could be applicable in cases of resistance applied by elastic bands or spotters.

In conclusion, dynamic warm-up exercises could be applicable in cases of resistance corresponding to 6-10% of body weight applied in horizontal and vertical directions in order to increase the jump performance acutely.

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