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Dynamic Warm-Up Protocols, With and Without a Weighted Vest, and Fitness Performance in High School Female Athletes

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Context: Recent authors have not found substantial evidence to support the use of static stretching for improving performance, so interest in dynamic warm-up procedures has risen. Our findings may improve the understanding of the acute effects of different types of pre-exercise protocols on performance and may help clinicians develop effective warm-up protocols for sports practice and competition.

Objective: To examine the acute effects of 4 warm-up protocols with and without a weighted vest on anaerobic performance in female high school athletes.

Design: Randomized, counterbalanced, repeated-measures design.

Setting: High school fitness center.

Patients or Other Participants: Eighteen healthy high school female athletes (age = 15.3 ± 1.2 years, height = 166.3 ± 9.1 cm, mass = 61.6 ± 10.4 kg).

Intervention(s): After 5 minutes of jogging, subjects performed 4 randomly ordered warm-up protocols: (1) Five static stretches (2 × 30 seconds) (SS), (2) nine moderate-intensity to high-intensity dynamic exercises (DY), (3) the same 9 dynamic exercises performed with a vest weighted with 2% of body mass (DY2), and (4) the same 9 dynamic exercises performed with a vest weighted with 6% of body mass (DY6).

Main Outcome Measure(s): Vertical jump, long jump, seated medicine ball toss, and 10-yard sprint.

Results: Vertical jump performance was significantly greater after DY (41.3 ± 5.4 cm) and DY2 (42.1 ± 5.2 cm) compared with SS (37.1 ± 5.1 cm), and long jump performance was significantly greater after DY2 (180.5 ± 20.3 cm) compared with SS (160.4 ± 20.8 cm) ($P \leq .05$). No significant differences between trials were observed for the seated medicine ball toss or 10-yard sprint.

Conclusions: A dynamic warm-up performed with a vest weighted with 2% of body mass may be the most effective warm-up protocol for enhancing jumping performance in high school female athletes.

Key Words: adolescents, static stretching, potentiation, power

Although static stretching has been theorized to enhance performance,[1,2] a number of authors have reported that an acute bout of pre-exercise static stretching may actually reduce anaerobic performance in adults through decreases in force[3,4] and power.[5–7] Recent findings indicate that pre-exercise static stretching may have similar consequences on muscle function in children and adolescents.[8–11] For example, McNeal and Sands[10] demonstrated that young gymnasts' lower extremity power was reduced when performance immediately followed static stretching, and Faigenbaum et al[8] reported that jumping and sprinting performance declined significantly in children after an acute bout of static stretching. Long-term static stretching increases the range of motion at a particular joint,[12] but it appears that warm-up protocols, including prolonged static stretching, might have unintended adverse consequences on anaerobic performance in young athletes. Indeed, the President's Council on Physical Fitness and Sports reported that static stretching might compromise performance.[13]

In the absence of sufficient evidence to endorse pre-event static stretching with respect to performance enhancement, attention has turned to warm-up procedures that involve the performance of dynamic movements designed to elevate core body temperature, enhance motor unit excitability, improve kinesthetic awareness, maximize active ranges of motion, and develop fundamental movement skills.[14–17] Warm-up dynamic exercise may create an optimal environment for power production by enhancing neuromuscular function. This phenomenon has been referred to as *postactivation potentiation* (PAP) and is believed to improve power performance.[18,19] Postactivation potentiation appears to have its greatest effect on fast-twitch fibers,[20,21] so it is most likely to affect activities such as jumping, sprinting, and throwing. This suggestion is consistent with the work of several authors who reported that pre-event protocols including moderate-intensity to high-intensity dynamic movements can enhance power performance in both youths[8–11] and adults.[7,20,22–25]

Previous authors[8–11] have compared the acute effects of pre-event static stretching and dynamic exercise on anaerobic performance in youths. Whether young athletes would benefit from performing a dynamic warm-up with a weighted vest is an intriguing question. Some coaches believe that the use of a weighted vest during training may recruit more muscle fibers and require more neural activation and, therefore, lead to an increase in athletic performance.[26,27] The use of weighted resistance (ie, a weighted vest or dumbbells) during a dynamic warm-up protocol enhanced jumping performance in collegiate athletes.[22,24] The effectiveness of weighted resistance during a dynamic warm-up for high school athletes who are physically less mature is unclear.

In some high school sports, even small changes in performance can have a dramatic effect on the outcome of an event. The possibility that a dynamic warm-up protocol with weighted resistance could result in even greater gains in power production could have important implications for certified athletic trainers and other professionals who typically encourage young athletes to engage in some type of warm-up before practice and competition. Accordingly, our purpose was to examine the acute effects of 4 warm-up protocols, with and without a weighted vest, on anaerobic performance in high school female athletes. Based on previous findings, we hypothesized that performance after dynamic warm-up protocols with a weighted vest would exceed performance after warm-up static stretching and dynamic exercise without a weighted vest.

METHODS

Design

We used a randomized, counterbalanced, within-subjects experimental design to compare the acute effects of 4 warm-up protocols, with and without a weighted vest, on anaerobic performance in female high school athletes. Before testing, subjects jogged for 5 minutes and then participated in one of the following 10-minute warm-up protocols in random order on nonconsecutive days: (1) static stretching (SS), (2) moderate-intensity to high-intensity dynamic exercise (DY), (3) moderate-intensity to high-intensity dynamic exercise with a vest weighted with 2% of body mass (DY2), or (4) moderate-intensity to high-intensity dynamic exercise with a vest weighted with 6% of body mass (DY6). The dependent variables were vertical jump, long jump, seated medicine ball toss, and 10-yard (9.14-m) sprint. Each testing session occurred at least 48 hours after a competition or hard practice session. In order to control for the learning effect that can result from repeated testing, we used a counterbalancing technique in which the order of the warm-up protocols was randomly assigned.

Subjects

Twenty females volunteered to participate in this study. However, 2 subjects did not complete all study procedures as a result of scheduling conflicts. The mean age, height, and body mass of the 18 subjects who completed all study procedures were 15.3 ± 1.2 years, 166.3 ± 9.1 cm, and 61.6 ± 10.4 kg, respectively. Body mass and height were measured using a calibrated balance scale (Detecto, Webb City, MO) and standiometer (Seca, Hanover, MD). All subjects were healthy interscholastic high school athletes (basketball, track, volleyball, lacrosse, or soccer players) who had prior experience in resistance training and performing dynamic exercises (without a weighted vest) as part of their physical education classes and sports practice sessions. Subjects with a chronic pediatric disease or an orthopaedic limitation were excluded. Subjects who were participating regularly in a strength and conditioning program agreed not to increase the intensity, volume, or frequency of their program during the study period. The methods and procedures used in this study were approved by the institutional review board for use of human subjects at the college, and all subjects and their parents completed a health history questionnaire. A parent signed an informed consent form, and each subject signed an informed assent form before testing.

Warm-Up Protocols

Before data collection, all subjects participated in an introductory session consisting of a review of all study procedures and familiarization with the weighted vest. We used the Xvest (Xtreme Worldwide Athletic Equipment, Katy, TX) for the dynamic warm-up protocols with added resistance. The Xvest is made of nylon and is adjustable through shoulder strapping and lateral straps for proper fit (Figure 1). The unloaded vest used in this study weighed 0.68 kg; individual weight pockets located in the front and back of the vest allowed for the secure placement of 0.45-kg cylindrical weights, which were used to increase the weight of the vest by 2% or 6% of body mass, to the nearest 0.45 kg. Thus, the overall loads (weight vest plus added cylindrical weights) for the dynamic warm-up protocols with added resistance were approximately 3% and 7% of each subject's body mass. During the introductory session, each subject wore a weighted vest (without added weight) and practiced several dynamic movements.

Subjects warmed up in groups of 2 or 3 under the close supervision of 1 research assistant and 1 physical education teacher, who demonstrated the proper technique for each static stretch or each dynamic movement during every warm-up trial. All study procedures took place in a high school gymnasium between 1:00 PM and 3:00 PM, and subjects refrained from participating in any vigorous physical activity for 48 hours before testing sessions. The 4 warm-up protocols were performed in random order and were administered on nonconsecutive days. Each warm-up protocol lasted a total of 15 minutes, of which the first 5 minutes consisted of jogging at a "comfortable pace" (rating of 9 or "very light" on the original Borg Rating of Perceived Exertion scale [28]). The jog was monitored by research assistants who asked subjects to report their rating of perceived exertion and, if necessary, to adjust their exercise intensity appropriately.

For ease of discussion, the 4 warm-up protocols will be referred to as protocol SS, protocol DY, protocol DY2, and protocol DY6. The amount of weight added to the vests for DY2 and DY6 was based on our prior experience using

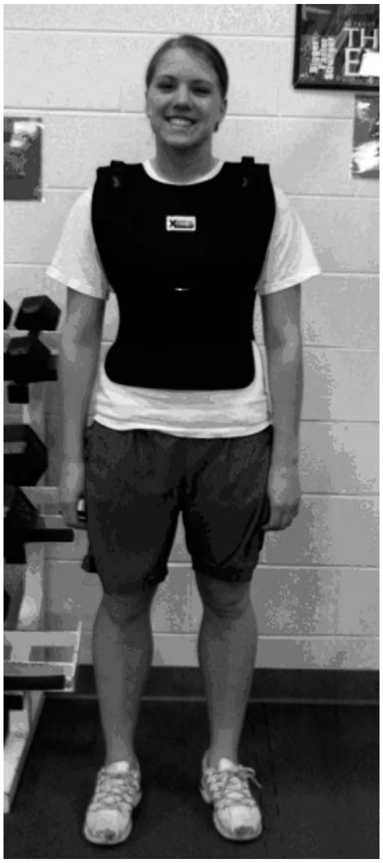

Figure 1. Weighted vest used for dynamic warm-ups with added resistance.

Table 1. Static Stretches

Stretch	Description
1. Hip and lower back stretch	Subjects sat on the floor with both legs extended in front of the body. They crossed the left leg over the right leg and kept the left foot flat on the floor. They then wrapped their arms around the left leg and pulled the leg toward the chest. The stretch was repeated on the other side.
2. Chest and hamstring stretch	Subjects sat on the floor with both legs extended in front of the body. They placed both extended arms behind the back and clasped hands. They then raised their arms toward the ceiling while bending at the hip toward the toes.
3. Lying quadriceps stretch	Subjects lay on the right side, with the body straight, and braced the head on the right arm. They flexed the left knee and brought the left foot toward the buttocks. After grasping the left ankle with the left hand, they gently pulled back while pushing the hips forward. The stretch was repeated on the other side.
4. Calf stretch	From a standing position facing a wall, subjects placed the right foot forward about 2 ft (0.61 m) from the wall and the left foot 3 to 4 ft (0.91 to 1.22 m) from the wall in a staggered stance. They placed both hands on the wall and leaned forward, keeping the left leg straight with the heel on the floor and the right knee slightly bent. The stretch was repeated on the other side.
5. Triceps and side-bend stretch	From a standing position, subjects crossed the right leg in front of the left leg and brought the right arm overhead with the elbow bent, so that the palm of the right hand was reaching between the shoulder blades. Subjects grasped the right elbow with their left hand and gently pulled as they bent slightly toward the left side. The stretch was repeated on the other side.

weighted vests with adult athletes and on conversations with youth coaches who currently use weighted vests for conditioning. The order of protocols was randomized among subjects, who were placed into 1 of 4 groups. The protocol testing order for groups 1, 2, 3, and 4 were SS-DY-DY2-DY6, DY-DY2-DY6-SS, DY2-DY6-SS-DY, and DY6-SS-DY-DY2, respectively.

Protocol SS consisted of 10 minutes of static stretching for the major muscle groups (Table 1). Subjects performed 5 stretches in a slow and deliberate manner. Subjects held each stretch for 30 seconds at a point of mild discomfort, relaxed for 5 seconds, and then repeated the same stretch for another 30 seconds before progressing to the opposite extremity (when necessary). Each subject's movement was monitored carefully during each stretch to ensure that it was performed correctly. The SS protocol used in this study was designed to be consistent with general stretching recommendations for youth and representative of a general warm-up routine used by physical education teachers and youth coaches.[2,29] Because subjects jogged for 5 minutes before SS, the design of this protocol did not allow us to isolate the independent effects of SS on fitness performance. However, we considered it inappropriate to perform SS in a rested state without some type of aerobic warm-up.

Protocol DY consisted of 9 dynamic exercises that progressed from moderate intensity to high intensity (Table 2). Subjects performed each dynamic exercise for a distance of 10 yd (9.14 m), rested about 10 seconds, and then repeated the same exercise as they returned to the starting point. Subjects were continually instructed to maintain proper form (eg, vertical torso, knees toward chest) while performing the dynamic movements. This protocol was designed to be similar to those warm-up protocols typically used to prepare athletes for sport participation.[14,16]

Protocol DY2 consisted of the same dynamic exercise protocol that was performed in DY. However, during protocol DY2, each subject wore a vest weighted with 2% of body mass (about 1.2 kg) during the entire dynamic warm-up protocol.

Protocol DY6 consisted of the same dynamic exercise protocol that was performed in DY. However, during protocol DY6, each subject wore a vest weighted with 6% of body mass (about 3.7 kg) during the entire dynamic warm-up protocol.

Fitness Tests

Subjects performed the vertical jump, long jump, seated medicine ball toss, and 10-yd sprint following standardized protocols.[30,31] The best score of 3 trials for each test (2 trials for the 10-yd sprint) was recorded to the nearest 1.0 cm or 0.01 second. The testing procedures used in this study were designed to be similar to testing procedures used in youth sport programs. All subjects had prior experience performing these tests as part of their physical education classes and sports training programs, so we did not include a practice session. We have a high degree of test-retest reliability (R = 0.93 to 0.97)

Table 2. Dynamic Warm-Up Exercises

Warm-Up Exercise	Description
1. Speed skips	While skipping forward, subjects emphasized speed of movement and vigorous arm action with both elbows at 90° of flexion.
2. Heel kicks	While moving forward, subjects rapidly kicked the heels toward the buttocks while emphasizing speed of movement and quick feet.
3. Toes in, toes out	While rapidly hopping forward, subjects turned the toes inward with the heels turned outward and then turned the toes outward with the heels turned inward. Emphasis was on hip rotation and speed of movement.
4. Trunk twists	Subjects placed both hands behind the head and rapidly hopped forward as they twisted their hips to the right and left. They maintained an upright position with the chest forward as they emphasized trunk rotation.
5. Skipping straight-leg toe touches	From a standing position with both arms extended in front of the body, subjects skipped forward as the left foot was raised toward the left hand and then the right foot was raised toward the right hand. Subjects skipped when switching from the left leg to the right leg. Emphasis was placed on the speed of movement and vigorous arm action with both elbows at 90° of flexion.
6. Drop squat carioca	From a standing position with feet close together, subjects hopped and landed with feet shoulder width apart and knees slightly bent. Then subjects rapidly moved laterally while crossing the feet in front of each other. The exercise was repeated in the opposite direction.
7. Push-ups	From a modified push-up position with the knees on a mat and the hands near the chest, subjects performed 3 push-ups at a controlled speed followed by 3 explosive push-ups in which they attempted to lift their hands and body off the mat.
8. Sprint series	From a standing position with the feet close together, subjects leaned forward and sprinted to the 5-yd (4.57-m) mark and then accelerated through the 10-yd (9.14-m) mark.
9. High knee skip	While skipping forward, subjects emphasized the height of each skip, high knee lift, and vigorous arm action with both elbows at 90° of flexion.

when administering these tests to young athletes in our sports programs.

Vertical Jump. The countermovement vertical jump was measured using the Vertec Jump Training System (Sports Imports, Hilliard, OH). The Vertec has 49 color-coded, movable vanes that are spaced 1.27 cm apart. Once the height of the Vertec was adjusted, subjects were instructed to jump as high as they could and touch the highest vane. The vertical jump was calculated by subtracting a subject's standing reach height from her maximal jump height.

Long Jump. The long jump was performed on a long jump mat. Subjects began the long jump with their toes behind the marked line fixed at the 0-cm mark on the mat. The distance from the rearmost heel strike to the starting line was measured.

Seated Medicine Ball Toss. The seated medicine ball toss was performed with a 4-kg medicine ball (circumference, 36 cm). The subjects sat on the floor with knees slightly bent and their backs against a wall. They were instructed to throw the ball as far as they could with both hands (similar to a chest pass) without trunk movement. Before each toss, the ball was coated with magnesium carbonate (eg, weightlifting chalk) so that when the ball landed on the floor, it left a distinctive mark allowing for a precise measurement.

10-Yard Sprint. The electronic Speed Trap II Timing System (Brower Timing Systems, Draper, UT) was used to time the 10-yd sprint. A pressure pad was placed under the thumb of the subject's hand in the starting position. The timing device started when the subject lifted her thumb off the pressure pad and stopped when she passed a laser light beam projected across the finish line.

After each warm-up protocol was completed, subjects had a recovery period of 2 minutes, during which time they removed the weighted vest (DY2 and DY6) and then walked to the first testing station. The same researchers tested the same subjects following the same test order (vertical jump, seated medicine ball toss, long jump, 10-yd sprint), which was based on the duration of each test item and the muscle groups involved. All subjects completed the test battery in less than 15 minutes. Each subject completed all study procedures within 14 days.

Statistical Analysis

Descriptive statistics for all fitness variables are expressed as mean ± SE. We calculated a 1-way, repeated-measures analysis of variance to analyze differences among criterion measures after the 4 warm-up protocols. To evaluate if an order effect existed for the assignment of the treatment protocols, the results from the first, second, third, and fourth testing sessions were also analyzed with a 1-way, repeated-measures analysis of variance. When a significant F value was obtained, post hoc comparisons were conducted via a least significant difference test to identify specific differences between criterion measures or testing sessions. Statistical significance was set at $P \leq .05$, and all analyses were carried out using the SPSS statistical package (version 11.0; SPSS Inc, Chicago, IL).

RESULTS

Performance on the vertical jump was significantly greater after protocols DY and DY2 than after protocol SS ($F_{3,68}$ = 2.97, P = .04; Figure 2). Performance on the long jump was significantly greater after protocol DY2 than after protocol SS ($F_{3,68}$ = 2.74, P = .05; Figure 3). Trends toward significance were observed for the vertical jump and long jump after DY6 as compared with SS (P = .07 and .08, respectively). No significant differences between warm-up trials were observed for the seated medicine ball toss or 10-yd sprint ($F_{3,68}$ = 2.05 and 0.30, and P = .11 and .82, respectively; Figures 4 and 5). No significant order effects were observed for the vertical jump, long jump, seated medicine ball toss, or 10-yd sprint over the 4 testing trials ($F_{3,68}$ = 0.35, 0.46, 0.68, and 0.25, respectively, and P = .79, .72, .56, and .86, respectively). Statistical power for the sample size used ranged from 0.71 to 0.91 for the seated medicine ball toss, long jump, and vertical jump. For the 10-yd sprint, statistical power was 0.28, presumably as a result of the short duration of the activity, which may not have permitted enough variation among trials.

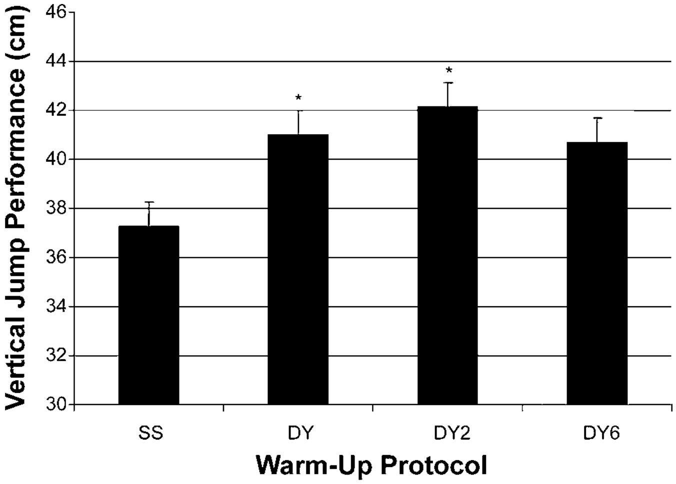

Figure 2. Vertical jump performance after 4 warm-up protocols. SS indicates static stretching; DY, dynamic exercise; DY2, dynamic exercise with a vest weighted to 2% body mass; DY6, dynamic exercise with a vest weighted to 6% body mass; and *, significantly different from SS, *P* ≤ .05.

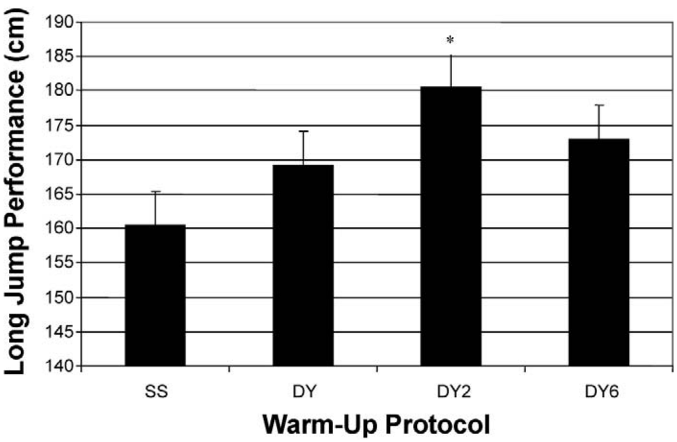

Figure 3. Long jump performance after 4 warm-up protocols. SS indicates static stretching; DY, dynamic exercise; DY2, dynamic exercise with a vest weighted to 2% body mass; DY6, dynamic exercise with a vest weighted to 6% body mass; and *, significantly different from SS, *P* ≤ .05.

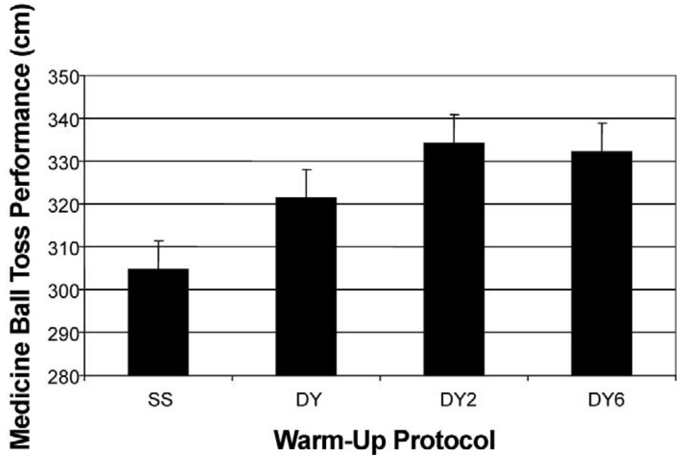

Figure 4. Seated medicine ball toss performance after 4 warm-up protocols. SS indicates static stretching; DY, dynamic exercise; DY2, dynamic exercise with a vest weighted to 2% body mass; and DY6, dynamic exercise with a vest weighted to 6% body mass.

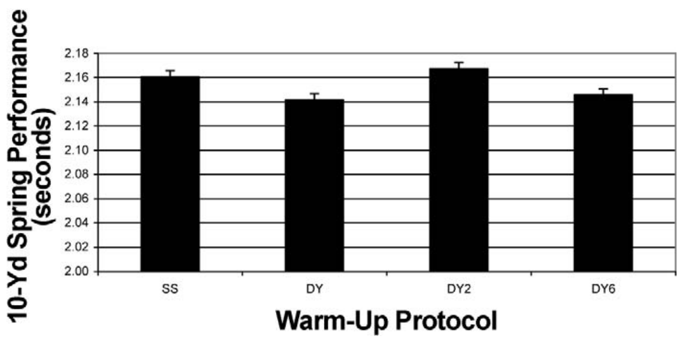

Figure 5. 10-yd sprint performance after 4 warm-up protocols. SS indicates static stretching; DY, dynamic exercise; DY2, dynamic exercise with a vest weighted to 2% body mass; and DY6, dynamic exercise with a vest weighted to 6% body mass.

DISCUSSION

Ours is the first study to examine the acute effects of 4 warm-up protocols, with and without a weighted vest, on anaerobic performance in a group of trained high school female athletes. The main finding was that warm-up protocols that included dynamic exercise resulted in superior performance on the vertical jump and long jump as compared with a warm-up protocol that included SS. These results are consistent with those of most, but not all,[32,33] investigators, who noted short-term improvements in performance after a bout of warm-up dynamic exercise compared with SS.[8,9,11,22,24] Our results are unique, however, in that we observed that DY2 may be the most effective dynamic warm-up for enhancing jumping performance in high school female athletes. Long jump performance improved by 12.5% after DY2 compared with warm-up SS. Furthermore, we noted that vertical jump performance improved by 10.1% and 13.5%, respectively, after DY and DY2 as compared with SS. These data are important to help identify the most effective warm-up protocols for high school athletes who perform activities that require a high power output.

To our knowledge, no other authors have examined the effects of dynamic warm-up protocols, with and without a weighted vest, on young female athletes. However, our results are consistent with those of other investigators who examined the effects of different dynamic warm-up protocols with added resistance on performance in adults.[22,24] Burkett et al[22] studied the effect of 4 warm-up protocols (submaximal jumps, weighted jump warm-ups with dumbbells [10% body mass], SS, and no warm-up) on vertical jump performance in college football players. The athletes performed significantly better (about 2.7%) after the weighted jump warm-up with dumbbells, as compared with the other protocols. Similar findings were reported by Thompsen et al,[24] who examined the acute effects of warm-up protocols, with and without a weighted vest (10% body mass), on jumping performance in collegiate female athletes. Performance on the long jump and vertical jump improved by 5.3% and 5.4%, respectively, after dynamic exercise with a weighted vest, as compared with warm-up SS. Furthermore, Thompsen et al[24] noted that long jump performance was significantly greater (2.5%) after warm-up dynamic exercise with a weighted vest than without a weighted vest. Although the rest interval (time between the end of the warm-up and start of the test) of 2 minutes was consistent between our investigation and these reports,[22,24] differences in the physical maturity of the subjects, training status, training age, and the design of the warm-up protocols (ie, intensity, volume [sets and repetitions], time under tension, and choice of exercises) could explain the differences between these findings and our results.

In our investigation, subjects wore vests weighted with 2% or 6% of their body mass during the entire 10-minute dynamic warm-up, which consisted of 9 movements. In both of the aforementioned reports involving adult athletes,[22,24] subjects performed a dynamic warm-up with an added resistance of 10% body mass. In one report,[24] subjects performed a series of 9 dynamic exercises during the warm-up period but only wore the weighted vest during the last 4 dynamic movements. In the other investigation,[22] the subjects held dumbbells as they performed a dynamic warm-up that consisted of 1 set of 5 countermovement jumps from the ground to a 63.5-cm–high box. It appears that the intensity, volume, duration, and type of these dynamic warm-up movements, as compared with those in our investigation, could explain, at least in part, the observed differences in performance. Because PAP and fatigue can coexist in skeletal muscle,[18] it appears that both the design of the warm-up protocol and the timing of the recovery period are critical variables to consider when developing dynamic warm-up procedures for athletes. Additional research is needed to explore the interaction among PAP, fatigue, and performance.

Our results demonstrate that DY2 may be most effective in preparing trained female high school athletes for activities involving jumping. Stronger, trained athletes may be better able to benefit from PAP,[23,25] so one could expect the subjects in our study (primarily basketball players and track athletes) to benefit from our dynamic warm-up protocols. Moreover, by adding resistance during a dynamic warm-up, the intensity of each dynamic movement increased, and, therefore, we suspect that a greater number of motor units were recruited to perform the desired action, which depended on explosive power.[19] When the subjects in our study removed the weighted vest before testing, it is possible that the potentiated response loaded the neuromuscular system and created a favorable environment for even larger gains in jumping performance.

Because excessive volume and/or load may result in fatigue, it is possible that DY6 was too fatiguing for the young subjects in our study. Although trends toward significance were observed for the vertical jump and long jump after DY6, as compared with warm-up SS, our findings indicate that the recovery interval in our study (2 minutes) was probably too short for this relatively intense warm-up protocol. Immediately after moderate-intensity to high-intensity dynamic exercise, PAP and fatigue increase, and then they gradually return to pre–warm-up levels.[19] If weighted vests with loads greater than 2% body mass are used during a dynamic warm-up for high school female athletes, a longer rest interval (greater than 2 minutes) between the end of the warm-up and the start of the test may enable the neuromuscular system to recover from fatigue but remain potentiated.

We found no significant differences in seated medicine ball toss ($P = .11$) or 10-yd sprint performance ($P = .82$) after the 4 warm-up protocols. Although some of our lower body dynamic skipping movements required vigorous arm action, only the power push-up specifically focused on the upper body. Thus, it appears that measures of upper body power performance, reaction time, and sprint speed are less likely to be affected, either positively or negatively, by the design of the warm-up protocol. It is also possible that the upper body of young female athletes requires a different type of dynamic warm-up to optimize performance. For example, a dynamic warm-up (with and without added resistance) that includes additional upper body power movements may result in more favorable findings in upper body power performance. As previously noted by other authors,[34] it is also possible that performance on longer sprints (eg, 50 m to 100 m) may be enhanced by a dynamic warm-up.

A limitation of our study is that we did not have a control condition with which to compare the other warm-up treatments. However, because participation in warm-up activities before exercise or sport is a universally accepted practice, we considered it inappropriate for young athletes to participate in anaerobic performance tests in a completely rested state. In addition, this investigation addressed the acute responses to different warm-up protocols in trained female high school athletes. Thus, our results should not be generalized to sedentary populations because an individual's training level may affect the response to PAP.[35]

Convincing scientific evidence supporting the performance-enhancing potential of SS is presently lacking. Thus, it may be desirable for young strength and power athletes to perform dynamic exercises (with and without a weighted vest) during the warm-up period. In our study, jumping performance improved about 13% after DY2, as compared with SS. The practical significance of the magnitude of this effect is impressive, because a 1% change in performance can have a significant effect on the outcome of a sporting event, particularly in track and field events. The portability of a weighted vest enhances the practical applicability of this device, and future authors should examine the short-term and long-term effects of different dynamic warm-up protocols with a weighted vest on performance. The results from these studies will help certified athletic trainers and other professionals to optimize warm-up procedures for athletes.

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REFERENCES

1. Holcomb B. Stretching and warm-up. In: Baechle T, Earle R, eds. *Essentials of Strength Training and Conditioning.* 2nd ed. Champaign, IL: Human Kinetics; 2000:321–342.
2. Martens R. *Successful Coaching.* 3rd ed. Champaign, IL: Human Kinetics; 2004.
3. Fowles JR, Sale DG, MacDougall JD. Reduced strength after passive stretch of the human plantarflexors. *J Appl Physiol.* 2000;89:1179–1188.
4. Kokkonen J, Nelson AG, Cornwell A. Acute muscle stretching inhibits maximal strength performance. *Res Q Exerc Sport.* 1998;69:411–415.
5. Cornwell A, Nelson AG, Heise GD, Sidaway B. Acute effects of passive muscle stretching on vertical jump performance. *J Hum Move Stud.* 2001; 40:307–324.
6. Cornwell A, Nelson AG, Sidaway B. Acute effects of stretching on the neuromuscular properties of the triceps surae muscle complex. *Eur J Appl Physiol.* 2002;86:428–434.
7. Young W, Jenner A, Griffiths K. Acute enhancement of power performance from heavy load squats. *J Strength Cond Res.* 1998;12:82–84.

8. Faigenbaum AD, Bellucci M, Bernieri A, Bakker B, Hoorens K. Acute effects of different warm-up protocols on fitness performance in children. *J Strength Cond Res.* 2005;19:376–381.
9. Faigenbaum AD, Kang J, McFarland J, et al. Acute effects of different warm-up protocols on anaerobic performance in teenage athletes. *Pediatr Exerc Sci.* 2006;17:64–75.
10. McNeal J, Sands W. Acute static stretching reduces lower extremity power in trained children. *Pediatr Exerc Sci.* 2003;15:139–145.
11. Siatras T, Papadopoulos G, Mameletzi D, Gerodimos V, Kellis S. Static and dynamic acute stretching effect on gymnasts' speed in vaulting. *Pediatr Exerc Sci.* 2003;15:383–391.
12. Taylor D, Dalton J, Seaber A, Garrett W. Viscoelastic properties of muscle-tendon units: the biomechanical effects of stretching. *Am J Sports Med.* 1990;18:300–309.
13. Knudson D. Current issues in flexibility fitness. *President Counc Phys Fitness Sports Res Dig.* 2000;3:1–6.
14. Mann D, Jones M. Guidelines to the implementation of a dynamic stretching program. *Strength Cond J.* 1999;21:53–55.
15. Rutledge I, Faccioni A. Dynamic warm-ups. *Sports Coach.* 2001;24:20–22.
16. Verstegen M, Williams P. *Core Performance.* Emmaus, PA: Rodale; 2004.
17. Young W, Elliott S. Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximal voluntary contractions on explosive force production and jumping performance. *Res Q Exerc Sport.* 2001;72:273–279.
18. Robbins DW. Postactivation potentiation and its practical application: a brief review. *J Strength Cond Res.* 2005;19:453–458.
19. Sale DG. Postactivation potentiation: role in human performance. *Exerc Sport Sci Rev.* 2002;30:138–143.
20. Gullich A, Schmidtbleicher D. MVC-induced short-term potentiation of explosive force. *New Stud Athl.* 1996;11:67–81.
21. Hamada T, Sale DG, MacDougal JD, Tarnoplosky MA. Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *J Appl Physiol.* 2000;88:2131–2137.
22. Burkett LN, Phillips WT, Ziuraitis J. The best warm-up for the vertical jump in college-age athletic men. *J Strength Cond Res.* 2005;19:673–676.
23. Duthie GM, Young WB, Aitken DA. The acute effects of heavy loads on jump squat performance: an evaluation of the complex and contrast methods of power development. *J Strength Cond Res.* 2002;16:530–538.
24. Thompsen AG, Kackley T, Palumbo MA, Faigenbaum AD. Acute effects of different warm-up protocols with and without a weighted vest on jumping performance in athletic women. *J Strength Cond Res.* In press.
25. Young WB, Behm DG. Effects of static stretching and practice jumps on explosive force production and jumping performance. *J Sports Med Phys Fitness.* 2003;43:21–27.
26. Cissik JM. Means and methods of speed training, part II. *Strength Cond J.* 2005;27:18–25.
27. Faccioni A. Assisted and resisted methods for speed development. In: Jarver J, ed. *Sprints and Relays.* 4th ed. Mountain View, CA: TAFNEWS Press; 1995:20–26.
28. Borg GA. Psychological bases of physical exertion. *Med Sci Sports Exerc.* 1982;14:377–381.
29. National Association of Sport and Physical Education. *Physical Education for Lifetime Fitness.* 2nd ed. Champaign, IL: Human Kinetics; 2005.
30. Harman E, Pandorf C. Principles of test selection and administration. In: Baechle T, Earle R, eds. *Essentials of Strength Training and Conditioning.* 2nd ed. Champaign, IL: Human Kinetics; 2000:275–307.
31. Safrit M. *Complete Guide to Youth Fitness Testing.* Champaign, IL: Human Kinetics; 1995.
32. Koch AJ, O'Bryant HS, Stone ME, et al. Effect of warm-up on the standing broad jump in trained and untrained men and women. *J Strength Cond Res.* 2003;17:710–714.
33. Unick J, Kieffer W, Cheesman W, Feeney A. The acute effects of static and ballistic stretching on vertical jump performance in trained women. *J Strength Cond Res.* 2005;19:206–212.
34. Nelson AG, Driscoll NM, Landin DK, Young MA, Schexnayder IC. Acute effects of passive muscle stretching on sprint performance. *J Sports Sci.* 2005;23:449–454.
35. Chiu LZ, Fry AC, Weiss LW, Schilling BK, Brown LE, Smith SL. Postactivation potentiation response in athletic and recreationally trained individuals. *J Strength Cond Res.* 2003;17:671–677.