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# Dynamic vs. Static-Stretching Warm Up: The Effect on Power and Agility Performance

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**Abstract.** McMillian, D.J., J.H. Moore, B.S. Hatler, and D.C. Taylor. Dynamic vs. static-stretching warm up: The effect on power and agility performance. *J. Strength Cond. Res. 20(3):492–499. 2006.*—The purpose of this study was to compare the effect of a dynamic warm up (DWU) with a static-stretching warm up (SWU) on selected measures of power and agility. Thirty cadets at the United States Military Academy completed the study (14 women and 16 men, ages 18–24 years). On 3 consecutive days, subjects performed 1 of the 2 warm up routines (DWU or SWU) or performed no warm up (NWU). The 3 warm up protocols lasted 10 minutes each and were counterbalanced to avoid carryover effects. After 1–2 minutes of recovery, subjects performed 3 tests of power or agility. The order of the performance tests (T-shuttle run, underhand medicine ball throw for distance, and 5-step jump) also was counterbalanced. Repeated measures analysis of variance revealed better performance scores after the DWU for all 3 performance tests ($p < 0.01$), relative to the SWU and NWU. There were no significant differences between the SWU and NWU for the medicine ball throw and the T-shuttle run, but the SWU was associated with better scores on the 5-step jump ($p < 0.01$). Because the results of this study indicate a relative performance enhancement with the DWU, the utility of warm up routines that use static stretching as a stand-alone activity should be reassessed.

**Key Words.** flexibility, performance testing, conditioning, calisthenics

## Introduction

Pre-exercise warm up routines are common practice, despite limited scientific evidence supporting one protocol over another. For this reason, warm up protocols tend to reflect the experience of individual coaches, trainers, and athletes. Traditionally, static-stretching exercises have been a prominent feature of warm up routines (6, 34, 37). Support for a more dynamic warm up (DWU) has grown in recent years, because several investigations have shown the potential for acute, static stretching to degrade performance on vertical jumps, short sprints, tasks requiring maximal voluntary contractions, muscle strength-endurance performance, balance challenges, and reaction time (2, 3, 6, 10, 11, 20, 21, 23, 27, 37). Additionally, several studies now indicate that pre-exercise static stretching does not offer the presumed benefit of injury risk reduction (5, 14, 17, 26, 30).

Smith (32) indicated that the general purpose of a pre-exercise warm up is to increase muscle and tendon suppleness, to stimulate blood flow to the periphery, to increase body temperature, and to enhance free, coordinated movement. Professionals in the strength and conditioning community have increasingly touted various DWUs as the best way to prepare athletes for the physical demands of their sport (12). Although many variations on the DWU theme exist, most feature progressive, continuous movement. Calisthenics such as squatting and lunging movements often are paired with running drills that include forward, lateral, and change-of-direction movement. Investigators have shown DWU to improve knee joint position sense, to increase oxygen uptake, to lower lactate concentration and raise blood pH, to improve efficiency of thermoregulation, and to improve performance for bicycle sprints and vertical jumps (1, 6, 7, 15, 20, 37).

Recently the United States Army Physical Fitness School (APFS) developed a DWU for individuals and military units. The stated objectives are to increase body temperature and heart rate, pliability of joints and muscles, and responsiveness of nerves and muscles in preparation for physical readiness training activities. This DWU was used before each exercise session as part of an intervention to decrease injuries and to improve physical performance among soldiers in a basic training battalion. Static stretching, a prominent feature of the warm up for generations of soldiers, was not included. Although multiple interventions confounded the effect of the DWU, injury rates over the 9-week training period were significantly decreased compared with both a control battalion and historic trends. Performance on physical fitness testing generally was improved (19).

Given the ubiquity of static stretching in warm up activities, the purpose of this study was to compare the effect of a DWU (based on the APFS model) with that of a static-stretching warm up (SWU) or no warm up (NWU) on selected measures of power and agility. Dependent variables to assess power and agility were chosen, because these attributes are common requirements for a variety of sports. The DWU protocol in this study closely mimicked the power and agility requirements of many sports, so we hypothesized that it would result in a performance enhancement relative to the SWU or NWU.

## Methods

### Experimental Approach to the Problem

All subjects attended a 2-part orientation session that included (a) instruction for active participation in both the DWU and SWU and (b) practice of the 3 performance measures (i.e., the T-drill, 5-step jump, and the medicine ball throw for distance). The independent variable was the type of warm up used before performance testing. The dependent variables were the scores on the 3 performance measures. During the orientation, subjects were given feedback to enhance proper execution of both the warm up techniques and the performance measures. To ensure that subjects had mastered the techniques for the performance measures, they repeated each of the 3 events until their scores no longer improved. Rest between trials of the T-drill lasted approximately 2 minutes. Rest between trials of the 5-step jump and medicine ball throw for distance was at the subject's discretion, but generally of 30–60 seconds' duration. Subjects were encouraged to take as long as necessary to recover from the previous effort.

### Subjects

Thirty cadets at the United States Military Academy (USMA) volunteered for and completed the study. Subjects were recruited from USMA club sports. Cadets were eligible for the study if they were fit for full military duty without restrictions. All subjects completing the study were members of rugby, lacrosse, or strength and conditioning teams. Members of the rugby and lacrosse teams were competing weekly. In addition, all cadets have routine physical requirements. For these reasons, the subjects were screened by the primary investigator before the study to establish eligibility and before each training or testing session to ensure continued eligibility. Exclusion criteria were: (a) acute impairment of the spine or lower extremities, vestibular dysfunction, or balance disorder, (b) history of surgery in either lower extremity, and (c) history of a neurological disorder affecting the upper or lower extremities. All subjects gave written, informed consent prior to participation in the study. The mean ± standard deviation (*SD*) for age, height, and weight for the 16 men were 20.2 ± 1.2 years, 182.4 ± 6.6 cm, and 88.8 ± 9.0 kg, respectively. The mean ± *SD* for age, height, and weight for the 14 women were 20.4 ± 1.5 years, 167.1 ± 7.9 cm, and 64.0 ± 7.8 kg, respectively. All subjects gave written informed consent prior to participation. The study was approved by the Human Subjects Research Review Board of Keller Army Community Hospital, West Point, NY.

### Warm Up Protocols

Subjects executed the warm up sessions in small groups with the primary investigator leading the DWU (Table 1) and an associate investigator (BH) leading the SWU (Table 2). The order in which the subjects performed the 3 warm up conditions was counterbalanced to avoid potential biasing effects associated with test sequence. Each warm up session lasted 10 minutes. Subjects scheduled for NWU rested in an area adjacent to the testing site.

### Performance Testing

Most recent investigations of pre-exercise stretching have used vertical jump tests as the measure of performance. The present investigation used other performance measures (Table 3) in order to evaluate agility as well as a broader spectrum of tasks requiring power. Care was taken to avoid tasks that would induce fatigue, because fatigue has been shown to hinder local muscular performance, especially for tasks that involve the stretch–shortening cycle.(18)

The 5-step jump was chosen as a measure of functional leg power. Single-leg hop tasks are used more commonly as functional tests; however, they are most often used to assess symmetry, and therefore normalcy, of the lower extremities following unilateral lesions, such as anterior cruciate ligament deficiency or reconstruction (9). For our purposes, symmetry was less important than were aggregate lower body power and stability. Wiklander et al. have shown the 5-step jump to be a reliable measure that correlates well with the vertical jump, long jump, and isokinetic leg strength (35).

The medicine ball throw for distance was chosen as a measure of total-body power. Stockbrugger et al. have shown this test to be a valid and reliable test for assessing explosive power for an analogous total-body movement pattern and general athletic ability (33).

The T-drill was chosen primarily as a measure of agility. For this test, the component tasks of (a) forward, backward, and lateral running; (b) stopping and changing direction; and (c) reaching with an upper extremity while lowering the center of gravity are all representative of commonly encountered tasks in sports. Pauole et al. have shown this test to be a valid and reliable measure of agility, leg power, and leg speed in college-age men and women (25). To emphasize lateral movement, the forward- and backward-run portions of the T-drill were set at 5 m rather than the 10-yd distance described by Pauole.

Data collection began the day after the orientation and ran for 3 consecutive days. Subjects performed 1 warm up protocol (DWU, SWU, or NWU) before data collection each day. Subjects were instructed to avoid exercise or vigorous physical exertion the morning of testing. All tests were conducted at 6 AM at the same test site each day.

After completing 1 of the warm up conditions (or 10 minutes of rest for the NWU group), subjects proceeded to the performance testing stations. The time between finishing the warm up and beginning the performance testing was approximately 2 minutes. The order of testing was counterbalanced to avoid carryover effects. A physical therapist or physical therapy assistant who was unaware of the subject's group assignment scored each performance test. None of the investigators participated in data collection. The primary investigator then compiled all data for analysis.

Attempts were made to control potentially confounding variables. For example, (a) testing occurred at 6 AM each day, with subjects advised not to eat or drink anything other than water before testing; (b) subjects were queried for injuries, illness, or excessive fatigue each day; (c) subjects were reminded of the importance of maximal effort each day before testing; (d) graders were either physical therapists or physical therapy assistants with at least 1 year of experience collecting performance measurement data for another study; and (e) graders received a standardized orientation to the measurements required for the study.

Ten subjects were removed from the study after completing the orientation: 2 subjects for excessive fatigue from cadet physical requirements the previous day, 2 subjects from injuries related to military training, and 6 subjects for missed testing sessions. No subjects were injured during the performance of either of the warm up conditions or performance testing.

### Statistical Analyses

Pre hoc power analysis was used to establish the appropriate sample size, based on the following parameters: effect size = 0.27 (based on previously reported data on the 5-step jump [35]), 3 degrees of freedom, power = 0.80, and alpha = 0.05. Repeated measures (2 [gender] × 3 [warm up protocol]) analysis of variance (ANOVA) was

**Table 1.** The dynamic warm up.

| Exercises | Execution |
|---|---|
| Calisthenics: Perform 10 repetitions of each exercise at a slow to moderate cadence unless otherwise indicated. All component movements are required for each repetition. | |
| Bend and reach | Reach high overhead. Squat and reaching between the legs, allowing the back to flex, but keeping the heels down. Return to the starting position. Perform at a slow cadence. |
| Rear lunge and reach | Start with hands on hips. Lunge to the rear while simultaneously reaching overhead. Return to the starting position in one motion. Repeat with the opposite leg. Keep most of the weight on the front leg. Lunge progressively further and deeper with each repetition. Keep the abdominals tight to maintain a stable trunk. Perform at a slow cadence. |
| Turn and reach | Stand with arms extended to the side at shoulder level with the palms up. Turn to the left and pause while keeping the pelvis facing forward. The arms should now be directed forward and rearward. Return to the starting position, then repeat to the other side. Keep the abdominals tight throughout. Keep the head directed forward throughout. Perform at a slow cadence. |
| Squat | Start with hands on hips. Squat until the thighs are parallel to the floor (or to your tolerance). Keep the heels on the floor. The arms should be raised to shoulder level for counterbalance. |
| Rower | Start in the supine position with arms overhead, head a few inches off the ground with the chin slightly tucked. In one motion, raise to a seated position, bend the knees to bring the feet flat, and bring the arms parallel to the ground. |
| Power jump | Start with the arms high overhead, with the feet, knees and hips aligned vertically. Squat and reach toward the ground with the arms outside the legs, keeping the back straight. Jump and reach overhead, landing in the squat position described above. Return to the starting position. |
| Prone row | From the prone position with the arms overhead and several inches off of the ground, begin by raising the chest slightly and bringing the hands back to shoulder level in a rowing motion. Maintain abdominal muscle tension throughout the exercise. The hands and elbows remain parallel to the ground at all times. Maintain the neck in a neutral position. |
| Push-up | At the starting position, the hands are directly under the shoulders or slightly wider. Elbows are straight, but not locked. The abdominals are contracted to maintain the trunk in line with the thighs. Do not lower the trunk past the point at which the upper arms are parallel to the ground. Perform at a moderate to fast cadence. |
| Windmill | From a relatively wide stance with the arms extended sideways and palms down, squat, bend forward and rotate the trunk to the left in order to reach the right hand to the left foot. Return to the starting position, then repeat to the opposite side. Keep the arms directed in opposite directions. Avoid excessive flexion of the spine. |
| Diagonal lunge and reach | Start with the arms high overhead. Lunge diagonally forward to the left while simultaneously lowering the hands to the lower leg. Return to the starting position in one motion. Repeat to the right. Keep the foot of the forward leg directed to the front, rather than in the direction of the lunge. Keep the trunk straight and the head up. Do not allow the knee of the forward leg to go beyond the toes or lateral to the foot. |
| Movement drills: Perform each exercise over a 20- to 25-m segment. Pause for 10–15 seconds of rest and return to the start point. This completes 1 repetition. Perform 1 repetition of each exercise. Maintain a slow to moderate pace unless otherwise indicated. | |
| Verticals | Run forward on the balls of the feet, raising the knees to waist level and maintaining a tall, upright stance. Use strong arm action to support the movement. Hands should move from waist to chin level with an approximately 90° bend in the elbows throughout. There should be no backswing of the legs with this drill. |
| Laterals | Stand perpendicular to the direction of movement, in a slight crouch with the back straight. Step to the side by rising slightly and bringing the trailing leg to the lead leg. Quickly hop to the side and land back in the crouch with the knees shoulder-width apart. Face the same direction for the down and back segments. |
| Crossovers | Stand perpendicular to the direction of movement, in a slight crouch with the back straight. Cross the trailing leg to the front of the lead leg and step in the direction of travel to return to the starting position. Then cross the trailing leg to the rear of the lead leg and step in the direction of travel to return to the starting position. Repeat this sequence to the 25-yd stopping point. Face the same direction for the down and back segments. Let the arms swing naturally side to side to support balance. Allow the hips to swivel naturally. |
| Skip | Step and then hop, landing on the same leg, followed by the same action with the opposite leg. Use strong arm action to support the movement. Hands should move from waist to chin level with an approximately 90° bend in the elbows throughout. When the right leg is forward, the left arm swings forward and the right arm is to the rear. When the left leg is forward, the right arm swings forward and the left arm is to the rear. |
| Shuttle sprint | Run at a moderate pace to the 25-yd line. When nearing the line, slow the movement, make a quarter-turn clockwise, plant the left foot parallel to the line, and squat or bend in order to touch the ground at the line. Run back to the starting line, turning counterclockwise to touch the ground with the right hand. Run back to and through the 25-yd line, gradually accelerating to near maximum speed. |

**Table 2.** The static-stretching warm up.*

| Stretches | Execution |
|---|---|
| Overhead arm pull | Raise the right arm overhead and place the right hand behind the head. Grasp below the right elbow with the left hand and pull to the left, leaning the body to the left. Repeat on the opposite side. |
| Turn and reach | Stand with arms extended to the side at shoulder level with the palms up. Rotate the trunk to the left while keeping the hips directed forward to bring the arms in line from front to rear. Keep the hips set and abdominal muscles tight throughout to prevent pelvic rotation. The head and eyes remain directed forward. Hold for only 10–15 seconds to avoid shoulder fatigue. Repeat in the opposite direction. |
| Rear lunge and reach | Step rearward with the left foot and reach overhead with both arms. This is the same position as the first movement of the rear lunge and reach in the dynamic warm up. Repeat on the opposite side. Maintain straightness of the back by keeping the abdominal muscles tight throughout the motion. Reach fully overhead with both arms. Arms should be shoulder width apart with palms facing each other with the fingers and thumb extended and joined. After the foot touches down on counts 1 and 3, allow the body to continue to lower. This promotes a better opening of the hip and trunk. |
| Hamstring stretch | Take a step forward with the left leg and reach toward the left foot by bending at the waist. Both knees are slightly bent and the arms are straight on either side of the forward leg. The trunk remains straight with the head in a neutral position. Repeat on the opposite side. |
| Calf stretch | Step forward 8–10 in. with the left foot and place the heel on the ground with the toes up. Bend forward and grasp the sides of the left foot with both hands. Gradually straighten the knee of the left foot and pull the ball of the foot back toward the shin. Attempt to keep the trunk straight with the head in a neutral position. Repeat on the opposite side. |
| Quadriceps stretch | Lie on the left side. Grasp the right ankle or foot with the right hand. Pull the right heel toward the buttocks and the thigh rearward. The right thigh may be further extended with pressure from the left foot. Repeat on the opposite side. Do not pull the heel forcefully to the buttock, especially if there is discomfort in the knee joint. In this case, achieve a beneficial stretch by allowing the knee to straighten slightly and pull the thigh further to the rear. |
| Posterior hip stretch | From the supine position, cross the right ankle over the left thigh. Grasp the right knee with both hands and pull it towards the left shoulder while raising the left knee toward the chest Repeat on the opposite side. |
| Trunk flexion/extension stretch | Part 1: Move to the quadruped position, then continue rearward to sit back onto the legs while keeping the arms extended to the front. The head remains passively flexed.<br>Part 2: Move to the prone position. Perform the prone press up from either the forearm or hands, depending on individual flexibility and comfort. The thighs and pelvis rest on the ground. Relax the back and abdominal muscles while bearing the bodyweight through the straight arms. Toes point to the rear. |

* Subjects performed 1 repetition of each stretch to each side. Stretches were held 20–30 seconds unless otherwise indicated.

**Table 3.** Performance tests and their description.*

| Test | Description |
|---|---|
| 5-step jump | From a parallel stance behind the starting line, subjects maximally jump from both legs to land on the left leg. Without stopping, maximally jump to the right leg, back to the left leg, back to the right leg and finally stopping with a 2-leg landing. The distance from the starting line to the back of the most rearward heel is recorded. The jump must be repeated if the subject falls backward on the final landing. Measurement was recorded to the nearest inch (based on preexisting floor markings) and converted to meters. The average of 2 trials was used for statistical analysis. Trials in which either graders or subjects noted execution errors were not recorded. |
| T-drill | Three cones are set 5 m apart on a straight line. A fourth cone is placed 5 m from the middle cone to form a "T." The subject starts at the cone at the base of the T. The grader gives the signal to go and starts the stopwatch. The subject runs to the middle cone and touches the cone, then side steps 5 m to the left cone and touches that cone. The subject side steps 10 m to the far right cone and touches that cone, then side steps 5 m back to the middle cone and touches that cone. The subject runs 5 m backwards past the base of the T. The grader stops the watch when the subject passes the base of the T. Measurement was recorded to 0.01 of a second. The average of 2 trials was used for statistical analysis. Trials in which either graders or subjects noted execution errors were not recorded. |
| Medicine ball underhand throw for distance | From a parallel stance behind the starting line, subjects maximally throw a 9-lb medicine ball using an underhanded toss. Subjects are encouraged to use countermovement as long as the feet remain parallel on the ground until the ball is released. The feet may leave the ground and cross the starting line as the ball is released. The grader will measure the distance from the starting line to the point where the ball first lands. Measurement was recorded to the nearest inch (based on preexisting floor markings) and converted to meters. The average of 2 trials was used for statistical analysis. Trials in which either graders or subjects noted execution errors were not recorded. |

* The order of testing was counterbalanced over the 3 days of testing.

**Table 4.** Performance on each dependent variable based on warm up conditions ($N = 30$). Data are mean ± *SD*.*

| | T-drill (s) | Medicine ball throw for distance (m) | 5-step jump (m) |
|---|---|---|---|
| Control (NWU) | 9.77 ± 0.82 | 9.47 ± 2.89 | 9.51 ± 1.14‡ |
| SWU | 9.69 ± 0.85 | 9.34 ± 2.87 | 9.78 ± 1.172‡ |
| DWU | 9.56 ± 0.79† | 9.79 ± 3.01† | 10.06 ± 1.23‡ |

* NWU = no warm up; SWU = static-stretching warm up; DWU = dynamic warm up.

† Denotes significant difference from the other 2 warm up conditions ($p < 0.01$).

‡ Denotes significant difference between all 3 warm up conditions ($p < 0.01$).

used to evaluate the effect of warm up conditions on the 3 performance measures. Tukey's honestly significant difference (HSD) was used for post hoc analysis. Statistical significance was set at $p \leq 0.05$.

## Results

Descriptive statistics representing the performance on each dependent variable based on warm up conditions are presented in Table 4. Repeated measures ANOVA revealed neither a significant main effect nor interaction for gender; therefore, data were collapsed for post hoc testing. The main effect for warm up protocol was significant. Pair-wise comparisons using Tukey's HSD revealed that subjects scored better after the DWU than after the NWU or SWU on all 3 performance tests ($p < 0.01$). There were no significant differences between the SWU and NWU for the medicine ball throw and the T-drill; however, subjects scored better after the SWU than after the NWU on the 5-step jump ($p < 0.01$).

## Discussion

The purpose of this study was to compare the effects of DWU, SWU, and NWU on selected measures of power and agility. Results indicate that the DWU conferred a modest performance enhancement for all 3 measures of power and agility relative to the SWU and NWU. These results are consistent with Bishop's review of the literature, indicating that an active warm up of moderate intensity is likely to significantly improve short-term performance on a range of tasks as long as fatigue is not induced (4). Although static-stretching warm up exercises have been shown to decrease power and one-repetition maximum strength tasks (21, 37), our results show no significant difference between the SWU and NWU for the T-drill and the medicine ball throw for distance. The SWU was a significant improvement over NWU for the 5-step jump.

In a review of the warm up literature, Bishop cites several reasons why an active warm up such as the DWU used in this study might improve short-term performance (4). Most factors are related to temperature and include decreased stiffness of the muscles and joints; increased transmission rate of nerve impulses; changes in the force-velocity relationship; and increased glycogenolysis, glycolysis, and high-energy phosphate degradation. In addition to these temperature-related changes, 2 neuromuscular phenomena possibly activated by the DWU could potentially enhance power and agility performance. Post-activation potentiation (PAP; an increase in muscle twitch force and rate of force development following a conditioning contractile activity) could theoretically improve power and agility performance, though the optimal parameters to exploit PAP are unknown (29). Similarly, postcontraction sensory discharge (increased neural activity measured in the dorsal roots following contraction) might enable a more rapid and forceful response to perturbations of muscle length (8). Active warm up also may decrease muscle stiffness by breaking the stable bonds between actin and myosin filaments, though stretching likely has the same effect (4, 34).

Although none of the physiological factors mentioned above were measured directly, we believe that the demands of the DWU used in this study are generally consistent with the recommendations of Bishop (4). For enhancement of short-term performance (10 seconds or less), evidence suggests a warm up of 5–10 minutes, performed at 40–60% of $\dot{V}O_2max$, followed by 5 minutes of recovery (4). Although the recovery interval used in the present study was less than Bishop's recommendation, fatigue did not appear to be significant in our athletic subjects.

In contrast to the benefits of an active warm up mentioned above, there are at least 2 theories why pre-exercise stretching might decrease subsequent performance relative to a more dynamic warm up. First, several researchers have cited reduced neural activation as a means by which repeated stretches reduce the number of motor units available for contraction (3, 11, 21). If the SWU reduced neural activation relative to the DWU, performance of power and agility tasks, such as those used in this study, might be diminished. Because neural activation was not measured, its effect on the performance measures used in this study is purely speculative.

In addition, other investigators have suggested that increased compliance (i.e., the length change that occurs when a force is applied) in the tendon results in a brief moment when muscle force is taking up slack within the tendon, rather than contributing to gross movement (14, 21). Potentially, such an effect could hinder power and performance. However, some studies have shown increased joint range of motion without changes in the compliance of the musculotendinous unit (16, 22), suggesting that greater stretch tolerance might account for the increased range of motion. Taylor et al. have shown that stretching and isometric contractions both result in subsequent relaxation of the muscle–tendon unit (34). This concept is supported by a clinical study in which 3 different warm up conditions (i.e., body-weight circuit exercises, static stretching, and proprioceptive neuromuscular facilitation stretching [PNF]) each resulted in equivalent increases in hamstring flexibility (6). This suggests that a dynamic warm up might increase flexibility from the resting state without the potential compromise of neural activation associated with an isolated, static-stretching warm up.

It is important to distinguish between pre-exercise stretching and flexibility training in general. The performance-related issues from pre-exercise stretching mentioned above, especially reduced neural activation, might not apply to stretching exercises performed at other times. In fact, investigations have noted improved performance correlated to regular stretching (31) and increased flexibility (36). Gleim et al., in a review of the literature on flexibility and sports performance, noted the sport-specific nature of flexibility, suggesting that flexibility training might enhance performance in sports that rely on extremes of motion for movement. Conversely, decreased flexibility might actually increase economy of movement in sports such as distance running, where only the mid-portion of the range of motion is used (14). The evidence suggests that flexibility training should be applied, based on individual needs and the physical demands of the activity.

Although the current investigation examined only the effect of warm up parameters on performance, injury prevention is cited routinely as a reason for pre-exercise warm up. As reported by Shrier (30), the recent epidemiological evidence suggests typical pre-exercise muscle stretching protocols do not produce meaningful reductions in risk of exercise-related injury. Conversely, basic science supports the notion that an active warm up might protect against muscle strain injury, though clinical research is equivocal on this point (14). Theoretically, warm up activities that enhance neural activation will better prepare muscles to absorb loads that might otherwise be transmitted to other structures such as ligaments, tendons, and the muscle cytoskeleton. This concept is supported by research showing that muscles under active contraction absorb significantly more energy than muscles at rest (13). Recently, Olsen et al. were the first to use a large, randomized, controlled study to show reduced rates of injury in a group performing a dynamic, functional warm up (24).

The following factors should be considered when interpreting the results of the present investigation. First, due to study design and restriction on the availability of subjects, only 3 repeated measures (one each following DWU, SWU, and NWU) were conducted. Therefore, the combined effect of dynamic and static stretching warm up components was not tested. Few studies have examined the effect of pre-exercise stretching combined with a dynamic component. Church et al. compared the effect of a general warm up consisting of a 10-minute circuit of body-weight exercises with the same warm up paired with either static-stretching or PNF stretches (6). Vertical jump performance was limited only by the PNF stretch warm up. The investigators theorized that the increased intensity of the PNF stretching might induce autogenic inhibition and, therefore, might limit vertical jump performance.

Rosenbaum et al. found that decreased force and rate of force development related to stretching was returned to normal after 10 minutes of running (28). This suggests that pre-exercise stretching may not hinder power performance if followed by dynamic movements that mimic the tasks that follow. Warm up protocols that combine dynamic and static-stretching exercises would add comparative value and are encouraged for future investigations. Still, for teams and individuals that are under time constraints for warm up, the current body of evidence suggests that static stretching might be unnecessary.

Another limiting factor of this study is that physiological parameters of the warm up protocols were not established. Controlling for factors such as muscle temperature and oxygen utilization would have allowed for greater precision when describing warm up parameters. Caution should be used when generalizing the results of this study to other populations. Our subjects were young athletes accustomed to vigorous athletic and military training;

older or less-athletic populations might respond differently to the warm up protocols used in this study.

Though evidence from previous investigations allows us to make general recommendations for the specificity, duration, intensity, and recovery interval of the warm up (4), questions remain as to the optimal parameters for these factors. Future clinical research should continue to investigate not only the optimal warm up parameters for duration, intensity, and recovery interval, but also the interplay of dynamic and static stretching components, sports specificity, environmental conditions, and psychological factors. In addition, more investigations are needed to establish the optimal warm up conditions for injury control.

## Practical Applications

For tasks requiring power and agility, the results suggest that a dynamic warm up might offer performance benefits not found with static stretching or no warm up. It is likely that a DWU similar to that used in this study will achieve general warm up goals without invoking the mechanical and neural activation drawbacks associated with acute, static-stretching. For tasks demanding a high degree of flexibility, power, and agility, warm up activities should be sequenced so that static-stretching (if it is deemed necessary) is followed by dynamic, progressive movements that mimic the goal activity without inducing fatigue.

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