Stretch-Induced Reductions in Throwing Performance Are Attenuated by Warm-up Before Exercise

Naryana C. Mascarin,[1] Rodrigo L. Vancini,[2] Claudio A.B. Lira,[3] and Marilia S. Andrade[1]

[1]*Department of Physiology, Federal University of Sao Paulo (UNIFESP), Sao Paulo, Brazil;* [2]*Physical Education and Sports Center (CEFD), Federal University of Espírito Santo (UFES), Vitoria (ES), Brazil; and* [3]*Human and Exercise Physiology Division, School of Physical Education and Dance, Federal University of Goias (UFG), Goiânia, Brazil*

Abstract

Mascarin, NC, Vancini, RL, Lira, CAB, and Andrade, MS. Stretch-induced reductions in throwing performance are attenuated by warm-up before exercise. *J Strength Cond Res* 29(5): 1393–1398, 2015—Recent investigations have suggested that static stretching (SS) performed before exercise reduces muscular performance. However, it is yet unknown whether dynamic warm-up exercises performed together with SS may actually minimize the detrimental acute effects of stretching on muscular performance. This study aimed to assess the effects of static shoulder stretching exercises, dynamic warm-up exercises, or both together, on muscular performance evaluated by ball throwing. Twenty-one female handball players (age: 16.2 ± 1.0 years [range: 14–18 years], height: 167.0 ± 10.0 cm [range: 158–179 cm], and body mass: 63.3 ± 7.6 kg [range: 50.4–77.4 kg]) performed SS, dynamic warm-up exercises or both, targeting the muscles of the upper limbs. Thereafter, medicine ball throwing distance and handball ball throwing speed tests were performed. Static stretching performed before the medicine ball throwing test reduced performance when compared with the warm-up exercises (95% confidence interval [CI] = 0.02–0.17, $p \leq 0.05$, effect size [ES] = 0.34). When a warm-up exercise routine was added to SS, the detrimental effects of SS were abolished (95% CI = −0.01 to 0.18, $p > 0.05$, ES = 0.31). The throwing speed was the same over the 3 conditions. In conclusion, warm-up exercises performed together with SS abolished the impairment in medicine ball throwing distance. We recommend that athletes perform warm-up exercises together with SS before activity to avoid detrimental effects on muscle strength.

Key Words muscle strength, stretching, handball, medicine ball

Address correspondence to Marilia S. Andrade, marilia.andrade@unifesp.br.

29(5)/1393–1398

Journal of Strength and Conditioning Research

Introduction

Stretching is commonly performed before exercise, and it is routine in a number of sports (3). There are various techniques for stretching, including ballistic, proprioceptive neuromuscular facilitation, static, and dynamic stretching (1). Among these, static stretching (SS) is widely used because its application is easy and safe (1). Static stretching usually involves moving a limb to the limit of its range of motion (ROM) and holding the stretched position 2 or 3 times for 15–60 seconds (28). One of the intended purposes of stretching before an athletic event is to ensure that the individual has a sufficient ROM in the joints to perform the athletic activity optimally (1).

However, recent investigations have suggested that SS performed before exercise, mainly when it lasts longer than 60 seconds, may reduce muscular performance (7,17,24,28). Stretch-induced reductions in performance are particularly evident in maximal and explosive muscular efforts that play an essential role in a variety of sports (9,10). These results have already made an impact on exercise professionals, who have begun to suggest that an alternative for SS should be considered in warm-ups before power activities (28).

However, stretching before an athletic event is also intended to decrease muscle stiffness or increase muscle compliance, thereby theoretically decreasing the risk of injury (2,15). In this context, strategies that maximize the positive effects of SS and minimize the adverse effects (reduction in muscular performance) need to be investigated.

Traditional dynamic warm-up exercises, performed through submaximal aerobic component (i.e., running, cycling) raise the body temperature up to 1–2° C (28), and this increment in body and muscle temperature has been found to increase nerve conduction velocity, enzymatic cycling and muscle compliance (28). Therefore, it is possible that associating submaximal aerobic exercises with SS in warm-up routines may minimize the deleterious effects of SS on muscular sperformance. It has been previously demonstrated that SS had a negative influence on explosive force and jumping performance, whereas SS associated with 4 minutes submaximal running and practice jumps minimizes the deleterious effects of SS on jumping performance (28).

However, there are no studies, to the best of our knowledge, which focus on whether dynamic warm-up exercises could also reduce the detrimental effects of SS on the muscular performance of the upper limbs. These findings would be of great importance for many overhead athletes and coaches of sports, such as swimming, handball, baseball, or athletic throwing (javelin and discus); if dynamic exercise is able to minimize the detrimental effects of SS, it can be used during warm-up routines before training sessions and matches. Hence, this study aimed to assess the acute effects on upper limb throwing performance of SS shoulder exercises, SS associated with dynamic warm-up exercises, or dynamic warm-up exercises only without stretching.

Methods

Experimental Approach to the Problem

Before the experimental procedures were undertaken, each athlete visited our laboratory to receive instructions about the study and to participate in a familiarization trial to practice throwing with a medicine ball and a handball ball in a handball court. These familiarization trials were preceded by dynamic warm-up exercises. Thereafter, on another day, the next intervention protocol was randomly assigned by drawing the order of the steps from an opaque envelope for (a) SS exercises, (b) dynamic warm-up exercises, and (c) SS associated with dynamic warm-up exercises. The test procedures were conducted on 3 nonconsecutive days within 1 week. Before (pre) and after (post) the intervention (a), (b), or (c), the ROM was evaluated to ensure that the SS was effective. After the intervention, (a), (b), or (c), ball throwing tests were administered (with medicine ball and handball ballsin this order). All data were collected before the training session, at the same time of day (at 2:00 PM). Subjects were instructed to have a light lunch before the test, to avoid intense physical training on the previous day and to sleep for at least 7 hours during the night before. Water intake was stimulated before and during the test.

In addition, results obtained from the familiarization test were compared with test results preceded by warm-up exercises without stretching to verify the test reproducibility.

Subjects

The subjects in this study were a convenient sample of 21 highly trained female handball players. The subjects had a mean age of 16.2 ± 1.0 years (range: 14–18 years), a mean height of 167.0 ± 10.0 cm (range: 158–179 cm), and a mean body mass of 63.3 ± 7.6 kg (range: 50.4–77.4 kg). From February to August 2011, athletes were recruited from the Olympic Center for Training and Research located in the city of …. The subjects had trained 4 days per week for at least 2 years, and each training session lasted approximately 2 hours. Their training focused on the development of technical and tactical skills that were specific to the sport and on the improvement of game-related fitness. The subjects were excluded from the study if they had had any shoulder pain or injury within the year leading up to the study.

All experimental procedures were approved by the University Human Research Ethics Committee and conformed to the principles outlined in the Declaration of Helsinki. After a clear explanation of the experimental procedures, including the risks and benefits of participation, written informed assent was obtained. For athletes younger than 18 years old, the parents or legal guardians were informed of the potential risks from this study and were required to sign a consent form. The subjects continued their regular training programs and were requested, with their coaches' consent, to refrain from strenuous workouts on the day before the test.

Static Stretching Exercises

To stretch the glenohumeral joint muscles in the dominant limb (limb dominance was determined by asking the subjects which limb they would naturally use to throw a ball), the following exercises were performed in this order: arm abduction at 90° with horizontal flexion to target the posterior deltoid fibers; shoulder abduction with the upper limb behind the head to target the triceps muscle; upper limb abduction to 135° with horizontal extension to target the pectoralis major muscle; upper limb abduction at 90° with horizontal extension to target the pectoralis minor muscle; and shoulder internal rotation with the hand behind the body to target the external rotator muscles. All the SS exercises were performed in 3 unassisted successive repetitions for 30 seconds up to threshold of mild discomfort, with no pain acknowledged by the athletes. Between each stretching repetition, during stretching exercises and at each muscle group change, the upper limb was given a 15-second rest period in a neutral position. After SS and before the dynamic warm-up exercises in intervention (c), there was a 15-second rest period.

Dynamic Warm-up Exercises

The warm-up exercises used in this study were given for dominant and nondominant upper limbs, and they were identical to those adopted in a previous study (18) for overhead athletes as follows:

Exercise 1 (shoulder external rotation):

- Strap an exercise band around a sturdy object (e.g., a fence) or have a partner hold it at shoulder height,
- Grasp the tubing handles in each hand (alternatively, you can loop the band around your wrist and hand),
- Raise your upper limbs out to your side and bend your elbows so that your hands are facing forward,
- Move your shoulder blades back together and simultaneously down your back towards your waist,
- Hold this shoulder blade position throughout the exercise,

- Rotate your forearms back until your hands are overhead,
- Repeat the exercise by slowly moving your forearms forward and back.

These dynamic warm-up exercises were repeated 10–20 times (1 repetition per second) before the test.

Exercise 2 (Lunge with multiplanar shoulder blade squeeze):

- Loop an exercise band around a sturdy object or have a partner hold it at shoulder height,
- Grasp the tubing handles in each hand (alternatively you can loop the band around your wrist and hand),
- Move into a lunge position with the left leg forward (if you are right-handed),
- Raise the upper limbs out to your sides with the elbows straight,
- Squeeze your shoulder blades together and simultaneously down your back towards your waist,
- Move your arms back and forth while keeping your hands up and your elbows straight.

These dynamic warm-up exercises were repeated 8–10 times (1 repetition per second) before the test.

The exercise should also be performed with 1 hand higher than the other.

Range of Motion

The shoulder's internal and external rotations range of motions (ROMs) were measured in degrees bilaterally in a supine position with a standard plastic long-armed 20-cm goniometer (Carci, São Paulo, Brazil). The central point of the goniometer (axis) was positioned on the olecranon process, a fixed arm was positioned perpendicular to the floor, and the other moving arm was aligned with the ulnar styloid process. To this end, the glenohumeral joint was moved at 90° of abduction in the coronal plane. The athletes maintained an internal rotation and an external rotation at the maximum of their ROM. The end range of internal rotation (IR) was determined as the point at which the posterolateral acromion was visualized to rise off the table (6).

Throwing Performance Test

As ball throwing speed is affected by muscular strength, we selected 2 throwing tests to evaluate whether a change in strength after the intervention is able to modify throwing effectiveness. The throwing tests were performed immediately after SS, dynamic exercises, or both.

Medicine Ball Throwing Test

The test began with the athlete facing forward with the medicine ball of 2 kg (Carci, São Paulo, Brazil) held in front of the chest with 2 hands. The feet were parallel, and toes were touching the measuring line. The subject threw the ball 3 times as far as possible. The distance (in meters) was measured from the front foot to where the ball landed. The results were obtained from the best of 3 throws. This test was performed after SS only, dynamic warm-up exercises only, and both exercises together.

Table 1. External and internal shoulder range of motion (in degrees) of handball athletes submitted to static stretching, warm-up, or both before and after intervention ($n = 21$).*†

	Internal rotation						External rotation					
Intervention	ROM before (°)	ROM after (°)	Mean change	95% CI	p	Effect size	ROM before (°)	ROM after (°)	Mean change	95% CI	p	Effect size
Warm-up	79.1 ± 7.8	82.4 ± 6.1	3.2 ± 7.5	−0.21 to 6.6	0.06	0.47	79.5 ± 7.8	77.3 ± 6.2	−2.2 ± 5.2	−4.6 to 0.2	0.06	0.31
Stretching + warm-up	76.2 ± 9.9‡	82.7 ± 8.8	6.5 ± 7.8	2.9 to 10.1	0.00	0.69	78.7 ± 5.6‡	83.3 ± 5.1	4.6 ± 4.5	2.5 to 6.6	0.00	0.85
Stretching	78.7 ± 5.3‡	82.4 ± 6.2	3.7 ± 4.0	1.9 to 5.5	0.00	0.64	78.0 ± 5.3‡	81.2 ± 4.7	3.2 ± 3.4	1.6 to 4.7	0.00	0.63

*ROM = range of motion; CI, confidence interval.
†Data are expressed as mean ± *SD*.
‡$p \leq 0.05$ (before < after).

Handball Ball Throwing Test

Immediately after the medicine ball throwing test, athletes performed the handball ball throwing test to measure the speed of the ball thrown. To this end, a radar gun (Stalker Sport; Stalker Radar, Plano, TX, USA) was used in accordance with a previous study (29). The subject threw the handball ball from a standing position 7 m from the goal. The ball used for the tests was International Handball Federation (IHF) size 2 (circumference: 54–56 cm and weight: 325–375 g). The testing procedure was conducted with the right upper limb (100% of the athletes were right-handed) and with left foot flat on the floor in front of the right foot. We oriented the athletes to throw the ball as fast as possible at the center of the goal. All subjects threw 5 times, and we used the mean values for analysis. The ball speed was measured in meter per second. This test was performed after SS only, dynamic warm-up exercises only, and both exercises together.

Statistical Analyses

The statistical analyses were performed using the software Statistic (version 6.0, 2002).

All variables presented normal distributions according to the Shapiro Wilk tests. All parametric data are presented as the mean ± *SD*.

To evaluate the influence of SS, dynamic warm-up exercise or both exercises on the IR or ER ROM, a Student's *t*-test for dependent variables was used. Intraclass correlation coefficients (ICCs) were calculated to determine the test-retest reliability for the 2 throwing tests. The ICCs were interpreted as follows: 0.90–0.99, almost perfect agreement; 0.70–0.89, strong agreement; 0.50–0.69, moderate agreement; 0.3–0.49, fair agreement; 0.0–0.29, poor agreement (21). Subsequently, differences between the 3 conditions (stretching vs. warm-up vs. stretching + warm-up) in throwing performance were analyzed with a 1-way analysis of variance. When a significant effect was achieved, the Tukey post hoc test was applied to determine the significance of the pairwise differences. The significance level (p) was set at 0.05 for all statistical procedures.

The effect size (ES) for changes in outcome measures after each intervention was assessed by the ES, calculated according to the following equation:

$$ES = (M2 - M1)/SD_{\text{pooled}},$$

where, ES is the effect size, M1 and M2 are the mean of the first and the second trial, and SD_{pooled} is the pooled *standard deviation*, calculated by dividing the mean difference by the *SD* of the pretraining measurement (8).

$$SD_{\text{pooled}} = \sqrt{(S_1^2 \times n_1 - 1) + (S_2^2 \times n_1 - 1)/(n_1 + n^2 - 2)}.$$

Threshold values for Cohen ES statistic were >0.2 (small), 0.5 (moderate), and >0.8 (large) (8).

Results

As expected, the internal rotation ROM assessed before SS was lower than the ROM assessed after SS exercises ($p \leq 0.05$) and after SS plus dynamic warm-up exercises ($p \leq 0.05$). The ESs for internal rotation ROM after SS and after SS plus dynamic warm-up exercises were similar and moderate (ES = 0.64 and 0.69, respectively). There were no significant differences in the ROM before and after dynamic warm-up exercises conducted without SS ($p > 0.05$) (Table 1). Similar results were obtained regarding the external rotation. The ROM also increased only when SS was used ($p \leq 0.05$ and $p \leq 0.05$, for SS or SS plus dynamic warm-up exercises, respectively) (Table 1), however ES for external rotation ROM after SS only was moderate (ES = 0.63), whereas after SS plus dynamic warm-up exercises, it was large (ES = 0.85). There were no significant differences in the external rotation ROM before and after dynamic warm-up exercises ($p > 0.05$) (Table 1).

The test-retest ICCs (test reproducibility results) for the medicine ball throwing test and for the handball ball throwing test were 0.70 and 0.72, respectively. Therefore, both were classified as strong agreement.

Performance in the medicine ball throwing test was affected by the type of exercise undertaken before the test ($F_{(2,40)} = 3.64$, $p \leq 0.05$). Acute SS exercises realized before the medicine ball throwing test reduced the distance reached when compared with data obtained after dynamic warm-up

Table 2. Throwing performance obtained after static stretching, warm-up, or both intervention ($n = 21$).*†

	Warm-up	Static stretching + warm-up	Static stretching	*p* for ANOVA test
Medicine ball throwing test (m)	2.86 ± 0.28	2.77 ± 0.29	2.76 ± 0.30‡	0.03
Handball ball speed during throw ($m \cdot s^{-1}$)	15.1 ± 1.8	14.9 ± 1.8	14.8 ± 1.6	0.55

*ANOVA = Analysis of variance.
†Data are expressed as mean ± *SD*.
‡$p \leq 0.05$ for Tukey test (Static stretching < warm-up).

exercise alone (95% confidence interval [CI] = 0.02–0.17; $p \leq 0.05$; ES = 0.34; Table 2).

When a dynamic warm-up exercise routine was added to the SS exercise before evaluation, no differences in the distance reached were found when compared with values reached after dynamic warm-up exercise alone (95% CI = −0.01 to 0.18; $p > 0.05$; ES = 0.31, Table 2).

The handball ball throwing speed was not different when we compared dynamic warm-up alone with SS exercises alone or with SS plus dynamic warm-up exercises ($F_{(2,40)} = 0.59$; $p > 0.05$).

Discussion

Static stretching exercises are traditionally recommended before physical exercise; however, more recently, this practice has been demonstrated to produce acute deleterious effects on muscular performance. It is therefore important to determine whether the association of SS with dynamic warm-up exercises is able to minimize the harmful effects of SS exercises. This study evaluated the acute effects of SS exercises, dynamic warm-up exercises associated with SS exercises, or dynamic exercises only on handball ball and medicine ball throwing performance.

In brief, the results revealed that the SS protocol used in this study was effective for increasing the ROM, and athletes who did not do the stretching presented unaltered ROM after warm-up, thereby demonstrating the effectiveness of SS. Static stretching decreased medicine ball throwing performance when compared with the test results obtained from warm-up performed with dynamic exercises without stretching. However, the ball speed during the handball ball throwing tests was not influenced by SS. As described previously (7,17), the SS exercises induced a negative acute effect on the distance that the medicine ball was thrown, whereas the corresponding acute effects of the SS exercises on handball ball throwing speed were stable. This is likely to have occurred because the medicine ball throw is more dependent on muscular strength than the handball ball throwing speed, which depends on several other factors too, such as pelvis and trunk rotation velocity and flexion (27) or internal shoulder rotation and elbow extension (26).

The first results of our study are consistent with those of previous studies concerning acute SS exercises performed before a strength test (7,24). However, some studies have reported no reduction in strength and power performance after SS (11,14,16,20), and some studies have even reported an improvement in performance (12). These conflicting results are most likely a consequence of the different stretching protocols used about intensity, frequency, and duration and different protocols of strength evaluation. It has been suggested that the minimal stretch duration required to provide a prolonged effect using static stretches is 4 minutes (22); however, there is clear evidence that a significant reduction is likely to occur with stretches ≥60 seconds (18) or ≥90 seconds (7). In our study, SS was maintained for 90 seconds (3 repetitions of 30 seconds with 15-second rest period in a neutral position), and this was sufficient to increase the ROM and to decrease the distance thrown in the medicine ball throwing test.

Although speculative, there are 2 main hypotheses to explain the acute and deleterious effects of stretching: (a) viscoelastic effects and (b) neural effects (19). Regarding viscoelastic effects, changes in the ROM and resistance to strength can be attributed to stress relaxation creep and hysteresis (19). This consequent decrease in resistance can be thought of as a decrease in the muscle stiffness or an increase in the muscle compliance, which may be useful for injury prevention, especially for muscular strain (2,15).

In terms of neural effects, it is apparent that when passive stretches are applied to skeletal muscle, there is minimal active contractile activity in response to the stretch (19,22), and the indices of motor neuron excitability are decreased (4,13). Interestingly, stretch-induced strength loss is, in part, attributed to a prolonged inhibitory effect of stretching (5). Decreased amplitude of the surface electromyography (EMG) signal during maximal voluntary contractions after stretching provides evidence that stretch-induced strength loss is a neural effect (5). Moreover, stretch-induced strength impairment has also been demonstrated in the contralateral nonstretched limb, suggesting that stretching-induced strength decrease may be due to a central nervous system inhibitory mechanism. (11). Because stretch-induced strength loss is, at least in part, due to neural effects, it is important to consider that dynamic warm-up exercises may represent other neural inputs to the muscle, which may potentially minimize the acute effects of SS.

Based on this shortcoming, a strategy that combines the potential positive impact of SS to reduce the risk of injury during exercise (23,25) with a strategy to minimize the negative effects of SS on strength performance would be useful. To this end, the novel finding of this study provides evidence for a protective factor of warm-up dynamic exercise, as the deleterious effects on muscular strength were abolished when warm-up exercise was associated with acute SS.

In summary, our results clearly show that SS before exercise had significant and practically relevant negative acute effects on muscular performance, as evaluated by a medicine ball throwing test, while the corresponding acute effects on handball ball throwing performance remained unaltered. However, warm-up exercises performed together with SS abolished this impairment in medicine ball throwing. Finally, this is the first study, to the best of our knowledge, which has investigated and compared the effects of a routine composed by pre-exercise SS associated with warm-up exercises with the effects of solely a SS routine on upper limb muscular performance.

Practical Applications

The results of this study might impact practice because dynamic warm-up exercises associated with stretching exercises before a strength effort minimize muscular strength impairment due to stretching exercises. Therefore, these results will be relevant to sports and exercise professionals who could recommend that SS exercise, provided it is properly developed, should be associated with dynamic warm-up exercises, especially during the periods before training/competition sessions.

Limitations

One limitation of this study is that we did not use objective measures of muscle function, such as those offered by the isokinetic dynamometer or EMG analysis. Isokinetic muscle testing is used by clinicians and exercise sports science professionals to assess muscle strength, power, and endurance. Therefore, the isokinetic dynamometer would allow a more detailed analysis about which variable from muscle function was impaired. Moreover, by using EMG would allow us to quantify the neural effects of the muscle stretching.

Our data indicate that the muscle power and maximal strength is impaired; however, we have no data regarding muscular endurance or muscular electrical activity.

Acknowledgments

The authors are grateful to the board of directors from the Olympic Center for Training and Research. They would also like to thank all of the athletes who volunteered their time to participate in the study and coach. The research was conducted at the Exercise Physiology Laboratory from UNIFESP, Brazil. Claudio A. B. Lira and Marilia S. Andrade authors contributed equally to this research and their citation order is interchangeable.

References

1. Alter, MJ. *Sports Stretch.* Champaign, IL: Human Kinetics, 1997.
2. Amako, M, Oda, T, Masuoka, K, Yokoi, H, and Campisi, P. Effect of static stretching on prevention of injuries for military recruits. *Mil Med* 168: 442–446, 2003.
3. American College of Sports Medicine (ACSM). *ACSM's Guidelines for Exercise Testing and Prescription.* Baltimore, MD: Williams and Wilkins, 2009.
4. Avela, J, Finni, T, Liikavainio, T, Niemelä, E, and Komi, PV. Neural and mechanical responses of the triceps surae muscle group after 1 h of repeated fast passive stretches. *J Appl Physiol (1985)* 96: 2325–2332, 2004.
5. Avela, J, Kyröläinen, H, and Komi, PV. Altered reflex sensitivity after repeated and prolonged passive muscle stretching. *J Appl Physiol (1985)* 86: 1283–1291, 1999.
6. Awan, R, Smith, J, and Boon, AJ. Measuring shoulder internal rotation range of motion: A comparison of 3 techniques. *Arch Phys Med Rehabil* 83: 1229–1234, 2002.
7. Behm, DG and Chaouachi, A. A review of the acute effects of static and dynamic stretching on performance. *Eur J Appl Physiol* 111: 2633–2651, 2011.
8. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, MI: Lawrence Erlbaum, 1988.
9. Cormie, P, McGuigan, MR, and Newton, RU. Developing maximal neuromuscular power: Part 1-biological basis of maximal power production. *Sports Med* 41: 17–38, 2011.
10. Cormie, P, McGuigan, MR, and Newton, RU. Developing maximal neuromuscular power: Part 2-training considerations for improving maximal power production. *Sports Med* 41: 125–146, 2001.
11. Cramer, JT, Housh, TJ, Weir, JP, Johnson, GO, Coburn, JW, and Beck, TW. The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. *Eur J Appl Physiol* 93: 530–539, 2005.
12. González-Ravé, JM, Machado, L, Navarro-Valdivielso, F, and Vilas-Boas, JP. Acute effects of heavy-load exercises, stretching exercises, and heavy-load plus stretching exercises on squat jump and countermovement jump performance. *J Strength Cond Res* 23: 472–479, 2009.
13. Guissard, N, Duchateau, J, and Hainaut, K. Mechanisms of decreased motoneurone excitation during passive muscle stretching. *Exp Brain Res* 137: 163–169, 2001.
14. Haag, SJ, Wright, GA, Gillette, CM, and Greany, JF. Effects of acute static stretching of the throwing shoulder on pitching performance of national collegiate athletic association division III baseball players. *J Strength Cond Res* 24: 452–457, 2010.
15. Hadala, M and Barrios, C. Different strategies for sports injury prevention in an America's Cup yachting crew. *Med Sci Sports Exerc* 41: 1587–1596, 2009.
16. Handrakis, JP, Southard, VN, Abreu, JM, Aloisa, M, Doyen, MR, Echevarria, LM, Hwang, H, Samuels, C, Venegas, SA, and Douris, PC. Static stretching does not impair performance in active middle-aged adults. *J Strength Cond Res* 24: 825–830, 2010.
17. Hopkins, WG. Measures of reliability in sports medicine and science. *Sports Med* 30: 1–15, 2000.
18. Kay, AD and Blazevich, AJ. Effect of acute static stretch on maximal muscle performance: A systematic review. *Med Sci Sports Exerc* 44: 154–164, 2012.
19. Liebenson, C, Crenshaw, K, and Shaw, N. Warm-up and training exercises for the overhead athlete. *J Bodyw Mov Ther* 12: 290–292, 2008.
20. McHugh, MP, Kremenic, IJ, Fox, MB, and Gleim, GW. The role of mechanical and neural restraints to joint range of motion during passive stretch. *Med Sci Sports Exerc* 30: 928–932, 1998.
21. Molacek, ZD, Conley, DS, Evetovich, TK, and Hinnerichs, KR. Effects of low- and high-volume stretching on bench press performance in collegiate football players. *J Strength Cond Res* 24: 711–716, 2010.
22. Munro, BH, Visintainer, MA, and Page, EB. *Statistical Methods for Health Care Research.* Philadelphia, PA: JB Lippincott, 1986.
23. Ryan, ED, Beck, TW, Herda, TJ, Hull, HR, Hartman, MJ, Costa, PB, Defreitas, JM, Stout, JR, and Cramer, JT. The time course of musculotendinous stiffness responses following different durations of passive stretching. *J Orthop Sports Phys Ther* 38: 632–639, 2008.
24. Shellock, FG and Prentice, WE. Warming-up and stretching for improved physical performance and prevention of sports-related injuries. *Sports Med* 2: 267–278, 1985.
25. Simic, L, Sarabon, N, and Markovic, G. Does pre-exercise static stretching inhibit maximal muscular performance? A meta-analytical review. *Scand J Med Sci Sports* 23: 131–148, 2013.
26. Smith, CA. The warm-up procedure: to stretch or not to stretch. A brief review. *J Orthop Sports Phys Ther* 19: 12–17, 1994.
27. Wagner, H, Buckecker, M, von Duvillard, S, and Muller, E. Kinematic description of the elite vs. low level players in team-handball jump throw. *J Sports Sci Med* 9: 15–23, 2010.
28. Wagner, H, Pfusterschmied, J, von Duvillard, S, and Muller, E. Performance and kinematics of various throwing techniques in team-handball. *J Sports Sci Med* 10: 73–80, 2011.
29. Young, WB and Behm, DG. Effects of running, static stretching and practice jumps on explosive force production and jumping performance. *J Sports Med Phys Fitness* 43: 21–27, 2003.