IJSPT

ORIGINAL RESEARCH

STATIC STRETCHING DOES NOT REDUCE VARIABILITY, JUMP AND SPEED PERFORMANCE

Fábio Carlos Lucas de Oliveira[1,2]
Luís Manuel Pinto Lopes Rama[2]

ABSTRACT

Background: Stretching is often part of the warm-up routine prior to athletic participation; however, controversial evidence exists on the effects of stretching on countermovement jump (CMJ) and sprint performance. Additionally, analysis of variability between repeated tasks is useful for monitoring players, to analyze factors that could affect the performance, and to guide clinical decisions for training strategies.

Purpose: The purpose of this study was to examine whether static stretching (SS) prior to CMJ and 20-meter (20-m) sprint would affect performance, and to investigate whether SS affects an athlete's ability to perform these tasks consistently.

Methods: Twenty-two trained healthy athletes (23.2 $\pm$ 5.0 years) attended, randomly, two testing sessions, separated by 48 hours. At session one, all participants underwent 10 minutes of dynamic running warm-up followed by the experimental tasks (three CMJ and three 20-m sprint), whereas five minutes of stretching was added after the warm-up routine at session two. All participants performed the same experimental tasks in both sessions. The stretching protocol consisted of five stretching exercises for each lower limb.

Results: The paired-samples t-test revealed no significant differences between the stretching protocol condition and no stretching condition for the 20-m sprint ($t(21) = .920$; $p = .368$) and CMJ ($t(21) = .709$; $p = .486$). There were no significant differences in trial-by-trial variability on 20-m sprint ($t(21) = 1.934$; $p = .067$) and CMJ scores ($t(21) = .793$; $p = .437$) as result of SS.

Conclusion: The SS protocol did not modify jumping and running ability in trained healthy athletes. The SS prior to training or competition may not cause detrimental effects to athletic performance.

Keywords: Counter movement jump, sports performance, sprint, static stretching, variability.

Level of evidence: Level III, Nonrandomized controlled trial.

[1] GRAME, Faculty of Medicine, Department of Kinesiology, Laval University, Québec, Québec, Canada
[2] Faculty of Sports Sciences and Physical Education, Research Center for Sport and Physical Activity, University of Coimbra, Coimbra, Portugal

The authors have no relevant conflict of interests to declare. The authors acknowledge the support from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES/ Science without Borders.

Acknowledgements: This investigation was conducted at the University of Coimbra, Portugal. Continuation of this work occurred in the Research Group of Movement and Ergonomics Analysis (GRAME) at Laval University, Québec, Canada. This study was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/ Science without Borders), under grant 13631-13-6. The authors have no conflict of interests.

CORRESPONDING AUTHOR
Fábio Carlos Lucas de Oliveira
Center for Interdisciplinary Research in Rehabilitation and Social Integration (CIRRIS)
Department of Rehabilitation, Faculty of Medicine, Université Laval
525 Boulevard Wilfrid-Hamel, local H-0610
G1M 2S8, Quebec City (QC), Canada.
Tel: +1 (418) 529-9141 extension 6043
E-mail: fabio-carlos.lucas-de-oliveira.1@ulaval.ca

INTRODUCTION

Planning an appropriate warm-up routine for an athletic team is a very important aspect of a coach's responsibilities[1] since it prepares the athletes, physiologically and mentally[2-4] for training and competition. Stretching is often part of the warm-up routine;[5,6] however, few studies has reported beneficial effects of stretching on performance.[7,8] Existing literature offers varied conclusions on the influence of stretching on jumping and speed performance. Both negative[4,9-15] and no effects[5,16-24] have been reported. In several cases, existing scientific evidence has not been taken into consideration with regard to stretching in the context of preparation for sports practice. For instance, to convince athletes about the importance of stretching prior to performing sports activities, coaches usually use empirical arguments that stretch improves performance, indirectly, by preventing injury.

Several authors have reported negative effects specifically with regard to vertical jump[9,13,15,25-31] and sprint performance.[32-35] Some hypotheses have been offered attempting to explain the negative effects of stretching on the neuromuscular system. According to Young & Behm[31] stretching possibly induces an increase in slack on the tendon through a decrease of musculotendinous stiffness. Church et al[36] suggested that the reduction of vertical jump performance may be related to the myogenic reflex, which causes a decrease in muscle power. In a review on the beneficial effects of stretching on performance, Shrier[37] concluded that a bout of stretching does not improve jump height and the results on speed tasks are controversial; however, it does not mean that it is detrimental to performance. In fact, the supposition that stretching is harmful to performance has led to the removal of SS from the warm-up routines of many athletes.[34] It may be that this kind of recommendation should be considered somewhat premature since the effects of SS prior to sports activities remain unclear.

The lack of consensus concerning the effect of SS on countermovement jump (CMJ) and 20-meter (20-m) sprint led the authors to investigate its influence on these functional abilities in order to examine whether SS is harmful to performance. Differing methodologies have been used to examine stretching effects on performance, such as varied stretching protocols (volume and intensity of stretching), numbers of performance trials, varied environmental conditions, and alterations in the rest period between each task. All of these factors may be responsible for generating divergence in the literature,[4,5,9,13,26,29-31,33,34,36,38,39] which hampers comparisons between investigations.

Athletes commonly use jump and sprint tasks as an assessment of their athletics skills.[40] Some authors argue that the analysis of variability can be useful to determine whether athletic enhancement occurs.[41] Because athletes wish to perform to the best of their ability or skill, it is also important to investigate whether stretching is a factor that may affect the athletes ability to perform usual tasks consistently. To the authors' knowledge, no study has addressed how stretching affects the variability in CMJ and sprint tasks. Expecting to achieve a better understanding of responsible factors for an irregular performance, trial-by-trial variability analysis in the 20-m sprint and CMJ was included in this experiment.

The purpose of this study was to examine whether static stretching (SS) prior to CMJ and 20-meter (20-m) sprint would affect performance and to investigate whether SS affects an athlete's ability to perform these tasks consistently. Based on previous studies,[30,40,41] the authors proposed the following hypotheses: 1) SS is detrimental to performance, which would be demonstrated by reducing CMJ height and 20-m sprint speed performance; 2) SS provides greater variability for both CMJ and 20-m sprint performance.

METHODS

All participants attended two testing sessions, completing three CMJ trials on a jump mat and three 20-m sprints on an indoor track, in each session. The Ergojump Platform (Globus Inc., Treviso, Italy) was used to measure the jumping time and indirectly the height reached in the CMJ by using the formula

$h = g * t^2 / 8$", where h is height, g is gravity ($g = 9.81\ m/s^{-2}$), and t is the full flight time.[42] For each CMJ, participants stood with hands on hips and feet parallel to landmarks on the mat of the Ergojump. They performed a squat with the knee in 90º of flexion[42] and then jumped to achieve maximum height. Subjects were encouraged to jump as fast as possible in order to minimize the coupling time between the eccentric and concentric phases,[9] making sure not to pause between the movements. They were instructed to keep the hands on their hips because the literature has shown that the arms contribution during the vertical jump can add 10% or more to the outcome.[9,43,44] They were also instructed to keep their hips and knees extended throughout the airborne part of the jump until the landing.[9,42]

Two pairs of photoelectric cells (Ergo Timer, Globus Inc., Treviso, Italy) were placed at 90 cm height and connected to an electronic motion sensor timer, which measured the time needed to complete 20-m sprint. For this task, participants remained upright standing, in a steady and comfortable position, with feet behind the first line of photoelectric cells, without any rocking movements of the body. Participants started running on a whistle sound. Of note, reaction time was not included in the measurement.

Participants

Twenty-two healthy men took part in the study (age: 23.2 ± 5.0 years; body mass: 82.8 ± 12.6 kg; height: 1.78 ± 0.06 m; BMI: 26.1 ± 2.8 kg/m^2). Participants were trained amateur athletes of different sports (e.g. handball, rugby sevens, etc.) and were recruited randomly through regional sports clubs. All of them were concurrently competing at the official national league of their sport. This population was recruited since their training and sport-specific participation often requires jump and speed abilities. Thus, it is expected they were familiar with the designed tasks (CMJ and 20-m sprint). To be included in the study, participants had to be: (a) aged 18 years or more; (b) physically active and registered as athlete at the official national league; (c) free of any medical condition or functional limitation that could compromise the testing tasks; (d) rested and not have performed any intensive physical activity for 48 hours prior to testing; (e) free of any injury or physical restriction at the time of testing. Researchers provided verbal encouragement at the same type and level for all players, to encourage maximal effort throughout testing. All participants received information about the research objectives and signed a consent form. The ethics committee of Faculty of Sports Sciences and Physical Education of the University of Coimbra approved this research, which is in agreement with the Helsinki declaration for experiences with humans.

Procedures

A summary of the experimental procedures is displayed in 1. At least three hours before testing, all participants joined a familiarization session with the measurement techniques and equipment. All participants underwent measurement of body weight (Body Scale 500, Seca Gmbh & Co. Kg., Hamburg, Germany) and height (stadiometer Seca Body-meter 206, Seca Gmbh & Co. Kg, Hamburg, Germany).

The data collection took place in two sessions separated by 48 hours to minimize fatigue effects on testing performance, in randomized order. Each day, before the experimental tasks, all participants performed a warm-up routine (dynamic running warm-up) similar to those performed for a normal training session. Dynamic warm-up consisted of the following exercises: a) jogging for one minute; b) skipping arm run for 30-sec; c) high knee run for 30-sec; d) knee flexion run (gluteal kicks) for 30-sec; e) sideways run for 30-sec; f) run with alternating squat for one minute; g) jogging forward/backward for two minutes; h) walking for one minute; i) running forward/backward for one minute; j) walking for one minute and trunk twist for one minute. It lasted 10 minutes and ended two minutes before the experimental tests began. The variability was calculated through analysis of the three trials of each condition, in both sessions.

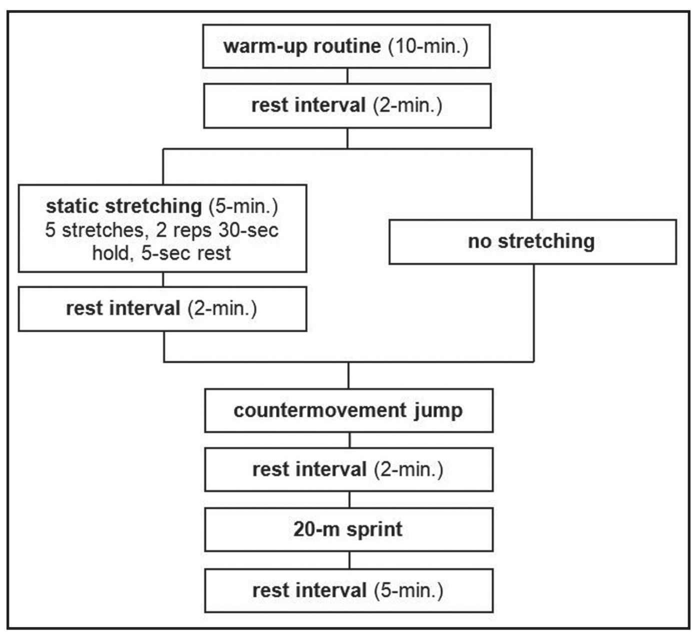

Figure 1. *A summary of the experimental procedures, adapted and modified from Young & Elliot (2001) and Unick et al. (2005).*

Stretching protocol

Despite several stretching protocols applied in the literature, the SS is the most common stretching variation used in the examination of the stretching effects on performance.[5,30,31,36,39] In this study, the SS was the only variation of stretching applied for a total time of five minutes after the warm-up. The stretching protocol followed the American College of Sports Medicine guidelines, and was chosen because it followed realistic parameters of stretching usually applied during the warm-up routine of athletes.[45] Each participant performed one set of the stretches for each target muscle (triceps surae, quadriceps, hamstrings, gluteus maximus and quadratus lumborum). Each stretching was held for 30 seconds, without any bouncing, before changing immediately to the contralateral side, Prior to each stretch, the researcher demonstrated how to properly perform the motion. Participants were instructed to reach the point of slight discomfort and keep a stationary position, at maximum possible length, until they approached the end of the range of motion.

During the entire experimental protocol, a supervisor assured that each stretching technique was being performed properly. Three trials of both CMJ and 20-m sprint were then performed, in randomized order, to reduce the possibility of bias. A rest of two minutes was given between the tasks, as well as five minutes rest period before performing a new repetition of CMJ and 20-m sprint. The authors expected that the recovery time established could be enough to eliminate the cumulative effect of fatigue suffered in each trial.

Calf Stretch, Hands against Wall. (Triceps surae). Stand facing a wall from some feet away. Stagger your stance, placing one foot forward with the knee bent, while keeping the back leg straight. . Lean forward and rest your hands on the wall, keeping your heel, hip and head in a straight line. Keep your heel on the ground with no bouncing. Switch sides.

Standing Quadriceps Stretch. (Quadriceps). Stand upright with one hand extended out against another participant, for balance. Flex your right knee and raise your heel to your buttocks. Grasp your right foot with one hand. Pull your heel towards your buttocks (no bouncing). Repeat with the left leg.

Standing Lower Back Stretch. (Quadratus lumborum). Stand upright with feet crossed and extend your arm overhead. Place the other hand on the contralateral hip, crossing your abdomen. Bend your trunk laterally to the opposite side of the arm that it is extended over the head. Switch sides.

Sitting Toe Touch One Leg. (Hamstrings). Sitting with the upper body nearly vertical, right knee extended and left knee bent. Lean forward and attempt to grasp the right foot toes or right ankles (depending on the limits of flexibility). Switch sides.

Ankle on the Knee. (Gluteus maximus). From a lying position, knees bent and feet kept on the floor, place an ankle on the opposite knee. Grasp the thigh or knee of the bottom leg and pull both of your legs into the chest. Relax the neck and shoulders. Switch sides.

Statistical Analyses

Descriptive data are expressed as mean $\pm$ SD. All data were stored in a database and exported to the Statistical Package for the Social Sciences version 17.0 (SPSS Inc., Chicago, IL, USA) for detailed statistical analysis. Initially, the normality was confirmed by the Shapiro-Wilk test, which both CMJ and 20-m sprint presented normal distribution ($p = .399$; $p = .266$, respectively). To examine the effect of the protocol on CMJ and 20-m sprint performance, with and without stretching, a Paired Samples t-test was used. Only the best performances for both conditions were taken for statistical analysis. Coefficient of variation quantified the variability of CMJ and 20-m sprint. Intraclass correlation coefficient (R) and the confidence intervals (95%) determined the reliability of the CMJ and 20-m sprint trials. Statistical significance was set at an alpha level (α) of 0.05.

Table 1. *Intraclass correlation coefficients (R) for the Countermovement Jump and 20-m Sprint*

	R (95% CI)
Countermovement Jump	
Static stretching (SS) – No stretching	.93 (.84 – .97)
20-m Sprint	
Static stretching (SS) – No stretching	.75 (.49 – .89)

R= intraclass correlation coefficient, CI= confidence interval

RESULTS

Performance results are shown in Table 2. For the CMJ, no significant differences were noted between both conditions (stretching protocol and without stretching protocol) in terms of height reached ($t(21) = .709$; $p = .486$). The speed to complete the 20-m sprint performance also did not demonstrate significant differences between the conditions analyzed ($t(21) = .920$; $p = .368$). Neither the CMJ and 20-m sprint presented significant trial-by-trial variability ($t(21) = .793$; $p = .437$; $t(21) = 1.934$; $p = .067$, respectively) when the conditions were compared.

DISCUSSION

Results of the current study add evidence to a much-discussed issue regarding the usage of stretching prior to training or competition. In the present study, SS did not reduce the CMJ or 20-m sprint performance refuting the hypotheses that SS would have a detrimental effect on the performance of both tasks and would provide greater trial-by-trial variability. The authors believe that the lack of effects seen after the protocol may be due the duration, volume, and intensity of stretching. This reasoning is in line with previous studies.[6,13,46] Stretching less than 30 seconds tends to not have an influence on performance in trained people.[47] Authors have reported that three sets of 15 or 45 total seconds of stretching are not enough to provide alterations of the viscoelastic properties of muscle-tendon units (MTU).[5,48] In addition, a study has been published that supported that 15 seconds has the same effectiveness than 45 or 60 seconds.[49]

Counter-Movement Jump

Current findings showed no significant effects of SS on CMJ performance ($p = .709$) (Figure 2), corroborating the observations from Shrier.[37] A decreased eccentric force is expected after SS, due to the positive correlation between the musculotendinous stiffness and eccentric muscle performance.[30] This could lead to a reduction in the jump performance. Based on this, Young & Behm[31] argued their results reporting negative effects of SS (2 sets x 30 s) on CMJ. An important observation is that, in their study, only two minutes rest was given following each trial. Differing recovery time between trials is likely the reason for different results between our study and Young & Behm,[31] since it is directly related to the recovery of motor neuron excitability, which has been presented as possible explanation for the unchanged performance following SS.[5] Possibly, the recovery time adopted in the current research allowed the neuromotor excitability return to its basal level. Following this line of reasoning, the intensity of stretching is supposed to affect the CMJ performance; however, it is likely that the volume and intensity, or even the type of stretching used in the current protocol, were not enough to provide any physiological changes. Thus, it seems that a decrease of eccentric force sufficient to affect performance on the CMJ was not achieved in this investigation.

Current findings also corroborate the results from several studies with regard to vertical jump outcomes.[5,16,18-24,46] The authors highlight the investigation from Unick et al,[5] who examined 18 female basketball players from NCAA Division III in three conditions (non-stretching, static and ballistic stretching). The authors did not find a significant decrease at the vertical jump for the SS condition. Despite this, the comparison between the current results and those of Unick et al is not simple since

Table 2. *Comparison between the mean scores for Countermovement Jump height and 20-m Sprint speed. Values are represented as mean ± SD*

	SS	NS	Test t	p-value
Performance				
Height – CMJ (cm)	36.09 ± 6.56	35.75 ± 5.69	.709	.486
Speed – 20-m Sprint	6.12 ± 0.32	6.08 ± 0.33	.920	.368
Trial-by-trial variability				
Height – CMJ (cm)	4.33 ± 3.24	3.43 ± 4.08	.793	.437
Speed – 20-m Sprint	.03 ± .06	.01 ± .01	1.934	.067

SS: static stretching protocol. NS: no stretching.

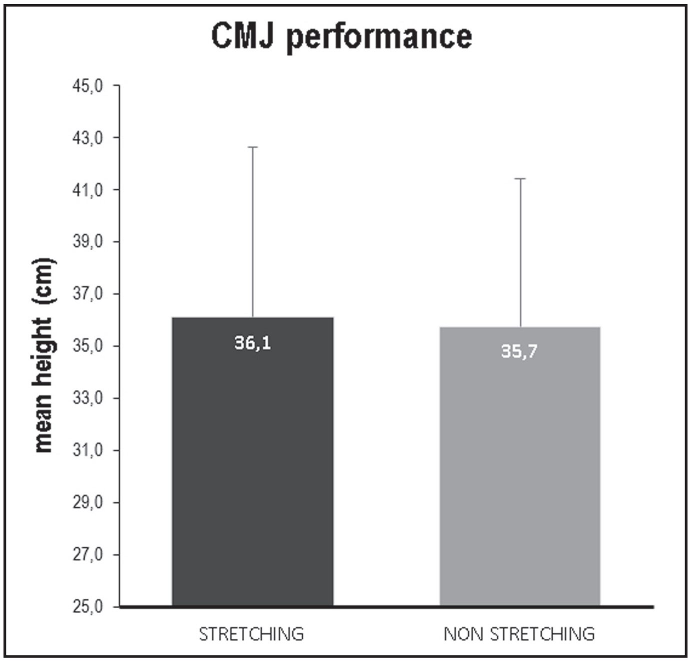

Figure 2. *Countermovement jump performance for both conditions (static stretching: 36.09 ± 6.56 cm and without stretching: 35.75 ± 5.69 cm). Data are presented by mean ± SD. No significant difference exists between the conditions for height reached in the CMJ (p = .486).*

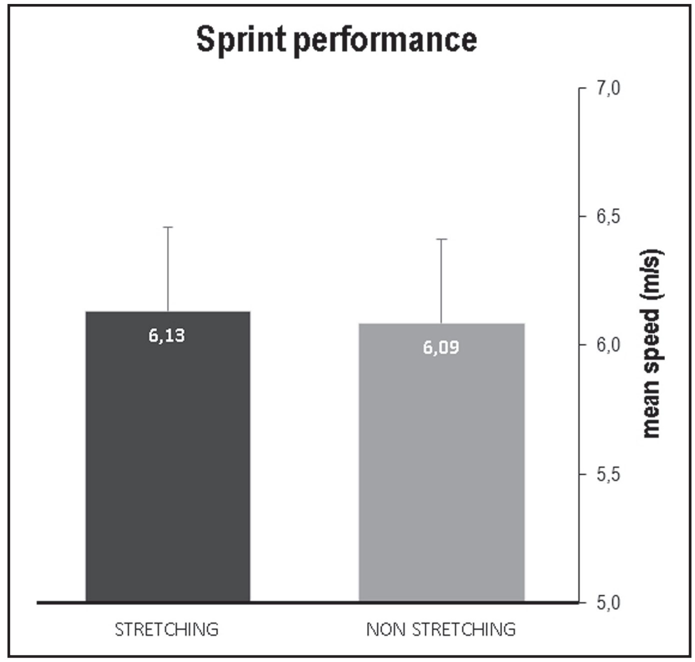

Figure 3. *Performance of control and experimental condition in 20-m Sprint (static stretching: 6.12 ± 0.32 m/s and without stretching: 6.08 ± 0.33 m/s). Data are presented by mean ± SD. No significant difference exists between the conditions (p = .368).*

methodological differences exist. For instance, Unick et al[5] used a sit and reach test plus five minutes warm-up jog, prior to the tests, both at a self-selected intensity. Moreover, they analyzed women only and some studies have shown that men tend to exhibit greater leg stiffness.[50] Finally, their SS protocol consisted of three sets of 15 seconds, followed by a rest period of 15 minutes.

20-m Sprint

It is important to highlight that the term "reduction" with regard to sprint performance, varies according to the outcome analyzed. When the outcome is the "time" necessary to complete a sprint task, the term reduction means improved performance, whereas measuring the "speed" achieved during the sprint task, reduction means decreased performance. In the current study, the outcome measure related to the 20-m sprint performance was the speed, which recorded how fast the participants ran.

The stretching protocol did not provide a significant reduction in 20-m sprint performance (p = .920) (Figure 3), corroborating results from two previous studies.[34,39] Wong et al[39] evaluated the 30-m sprint performance of 20 soccer players after an SS protocol and found no negative effects caused by the SS. Little & Williams,[34] submitted 18 soccer players to three different protocols (static stretching, dynamic stretching, and no stretching). Like Wong et al,[34,39] Little & Williams[34] did not find evidence that SS has a detrimental effect on sprint performance when included in a warm-up session.

Variability

Although a number of studies have examined the stretching effect on 20-m sprint speed and CMJ height performance, variability in these variables has not been ascertained. The current data adds information regarding the influence of SS on the variability of task performance, which is a missing issue in the literature. From the motor control perspective, it is supposed that extensive practice could provide better motor skills[51] and more consistency in performing usual tasks. This would mean greater CMJ height, greater speed in the 20-m sprint and less variability between all measurements. Tasks performed often during daily training tend to present minimal or no variability in response to training. In contrast, the expected negative effects of stretching should cause inconstancy in the performance, and hence increase variability. The hypothesis that the SS group would demonstrate greater trial-by-trial variability was not confirmed as no statistically significant differences were found in trial-by-trial analysis of the either the CMJ or the 20-m sprint ($t(21) = .793$; $p = .437$; $t(21) = 1.934$; $p = .067$, respectively) (Figures 4 and 5).

One of the possible reasons for these results is the standardized resting period, established in the curren investigation. The authors believe that this period might have allowed the return of the neuromotor excitability to its prestretching physiological status, since it has been suggested that a recovery interval greater than five but less than 15-20 minutes may provide ergogenic effects on short-term performance.[52]

Understanding the variability may bring interesting information for guiding a clinical decision making for training strategies.[41] Variability of performance can be used for monitoring players, as well as designing and analyzing factors that could affect the athletic performance.[53,54] Knowledge regarding variability emerges as useful information for the training of athletes, especially those involved in sports that require speed and jump skills throughout training and competition.

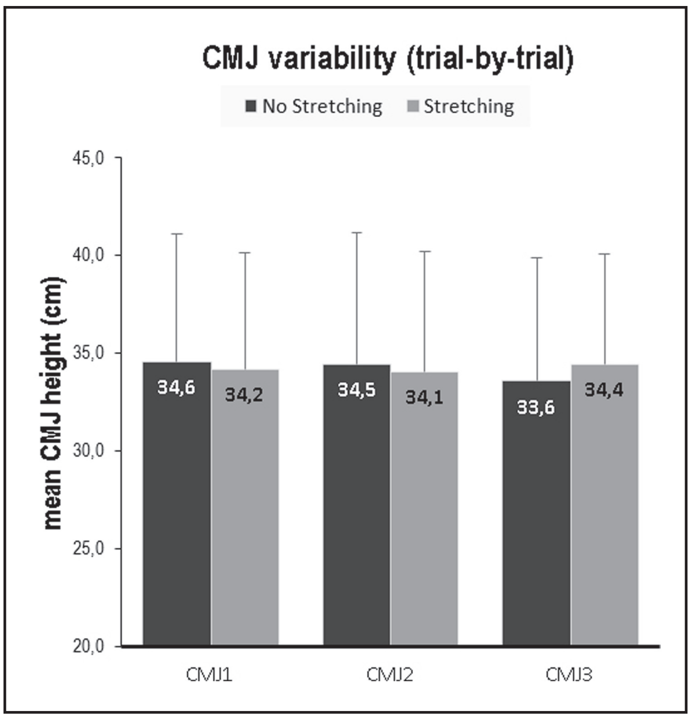

Figure 4. *Performance in the three trials for the CMJ. Data are presented by mean ± SD. No significant difference exists between the trials and conditions (p = .437).*

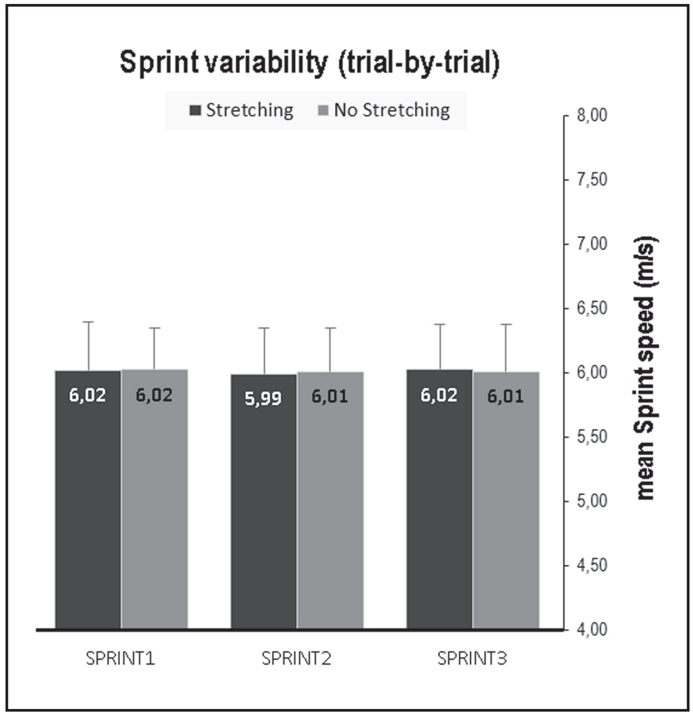

Figure 5. *Performance in the three trials for the 20-m Sprint. Data are presented by mean ± SD. No significant difference exists between the trials and conditions (p = .067).*

Limitations

Despite the rigorous methodological approach supported by a well-designed stretching protocol, some limitations were identified. For instance, only lower limbs were analyzed and, because the muscles fibers of the upper limbs present different characteristics, the effects of stretching on performance might be different. In addition, the performance in different sports was not compared and the specificity of each sport may affect the learning effects of CMJ and sprint tasks, which may have directly affected performance.

Future research

The effects of other stretching techniques on sports performance should be examined using the described experimental protocol in order to expand the scope of this analysis. In addition, upper limb stretches and the physiological mechanisms regulating the effects of stretching on CMJ and 20-m sprint should be further investigated to expand the results. The magnitude of acute effects of SS should be compared with the effects that may have been induced by other warm-up components. Comparison between different stretching magnitude and intensity, as well as different duration and volume of stretching prior to training, should be also further examined in order to identify potential influence on performance.

CONCLUSION

The results of the current study provide evidence that SS does not reduce jumping and sprinting performance when performed after a warm-up routine. The authors concluded that SS, under the experimental conditions applied in the study, did not cause any detrimental effects on either the CMJ or the 20-m sprint. Additionally, SS does not lead to significant changes in the trial-by-trial variability of CMJ or 20-m sprint performance.

REFERENCES

1. Young WB. The use of static stretching in warm-up for training and competition. *Int J Sports Physiol Perf.* 2007;2:212-216.
2. Safran MR, Garrett WE, Seaber AV, Glisson RR, Ribbeck BM. The role of warmup in muscular injury prevention. *Am J Sports Med.* 1988;16:123-129.
3. Young W, Behm D. Should static stretching be used during a warm-up for strength and power activities? *Nat Strength Condit Assoc.* 2002;24(6):33-37.
4. Taylor K-L, Sheppard JM, Lee H, Plummer N. Negative effect of static stretching restored when combined with a sport specific warm-up component. *J Sci Med Sport Sports Med Australia.* 2009;12:657-661.
5. Unick J, Kieffer HS, 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.
6. Young W, Elias G, Power J. Effects of static stretching volume and intensity on plantar flexor explosive force production and range of motion. *J Sports Med Phys Fitness.* 2006;46:403-411.
7. Pacheco L, Balius R, Aliste L, Pujol M, Pedret C. The acute effects of different stretching exercises on jump performance. *J Strength Cond Res.* 2011;25(11):2991-2998.
8. Sandberg JB, Wagner DR, Willardson JM, Smith GA. Acute effects of antagonist stretching on jump height, torque, and electromyography of agonist musculature. *J Strength Cond Res.* 2012;26(5):1249-1256.
9. Cornwell A, Nelson AG, Heise G, Sidaway B. The acute effects of passive muscle stretching on vertical jump performance. *J Hum Mov Stud.* 2001;40:307-324.
10. Curry BS, Chengkalath D, Crouch GJ, Romance M, Manns PJ. Acute effects of dynamic stretching, static stretching, and light aerobic activity on muscular performance in women. *J Strength Cond Res.* 2009;23(6):1811-1819.
11. Fletcher IM, Monte-Colombo MM. An investigation into the possible physiological mechanisms associated with changes in performance related to acute responses to different preactivity stretch modalities. *Appl Physiol Nutrit Metab.* 2010;35(1):27-34.
12. Hunter JP, Marshall RN. Effects of power and flexibility training on vertical jump technique. *Med Sci Sports Exerc.* 2002;34(3):478-486.
13. Pearce AJ, Kidgell DJ, Zois J, Carlson JS. Effects of secondary warm up following stretching. *European J Appl Physiol.* 2009 2009;105:175-183.
14. Wallmann HW, Mercer JA, Landers MR. Surface electromyographic assessment of the effect of dynamic activity and dynamic activity with static stretching of the gastrocnemius on vertical jump performance. *J Strength Cond Res.*2008;22(3): 787-793.
15. Wallmann HW, Mercer JA, McWhorter JW. Surface electromyographic assessment of the effect of static stretching of the gastrocnemius on vertical jump performance. *J Strength Cond Res.* 2005 2005;19:684-688.
16. Bazett-Jones DM, Gibson MH, McBride JM. Sprint and vertical jump performances are not affected by six weeks of static hamstring stretching. *J Strength Cond Res.* 2008;22(1):25-31.
17. Brandenburg J, Pitney WA, Luebbers PE, Veera A, Czajka A. Time course of changes in vertical-jumping ability after static stretching. *Int J Sports Physiol Perform.* 2007;2(2):170-181.
18. Carvalho FL, Carvalho MC, Simao R, et al. Acute effects of a warm-up including active, passive, and dynamic stretching on vertical jump performance. *J Strength Cond Res.* 2012;26(9):2447-2452.
19. Dalrymple KJ, Davis SE, Dwyer GB, Moir GL. Effect of static and dynamic stretching on vertical jump performance in collegiate women volleyball players. *J Strength Cond Res.* 010;24(1):149-155.
20. Frantz TL, Ruiz MD. Effects of dynamic warm-up on lower body explosiveness among collegiate baseball players. *J Strength Cond Res.* 2011;25(11):2985-2990.
21. Kinser AM, Ramsey MW, O'Bryant HS, Ayres CA, Sands WA, Stone MH. Vibration and stretching

effects on flexibility and explosive strength in young gymnasts. *Med Sci Sports Exerc.* 2008;40(1):133-140.

22. Murphy JR, Di Santo MC, Alkanani T, Behm DG. Aerobic activity before and following short-duration static stretching improves range of motion and performance vs. a traditional warm-up. *Appl Physiol Nutrit Metab.* 2010;35(5):679-690.
23. Perrier ET, Pavol MJ, Hoffman MA. The acute effects of a warm-up including static or dynamic stretching on countermovement jump height, reaction time, and flexibility. *J Strength Cond Res.* 2011;25(7):1925-1931.
24. Samuel MN, Holcomb WR, Guadagnoli MA, Rubley MD, Wallmann H. Acute effects of static and ballistic stretching on measures of strength and power. *J Strength Cond Res.* 2008;22(5):1422-1428.
25. Behm DG, Bradbury EE, Haynes AT, Hodder JN, Leonard AM, Paddock NR. Flexibility is not related to stretch-induced deficits in force or power. *J Sports Sci Med.* 2006 2006;5:33-42.
26. Behm DG, Kibele A. Effects of differing intensities of static stretching on jump performance. *Eur J Appl Physiol.* 2007 2007;101:587-594.
27. Cornwell A, Nelson AG, Sidaway B. Acute effects of stretching on the neuromechanical properties of the triceps surae muscle complex. *Eur J Appl Physiol.* Mar 2002 2002;86:428-434.
28. Nelson AG, Cornwell A, Heise G. Acute stretching exercises and vertical jump stored elastic energy. *Med Sci Sports Exerc.* 1996;28:156.
29. Vetter RE. Effects of six warm-up protocols on sprint and jump performance. *J Strength Cond Res.* 2007 2007;21:819-823.
30. Young W, Elliott S. Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximum voluntary contractions on explosive force production and jumping performance. *Res Quart Exerc Sport.* 2001;72:273-279.
31. Young WB, Behm DG. Effects of running, static stretching and practice jumps on explosive force production and jumping performance. *J Sports Med Phys Fitness.* 2003;43:21-27.
32. Fletcher IM, Anness R. The acute effects of combined static and dynamic stretch protocols on fifty-meter sprint performance in track-and-field athletes. *J Strength Cond Res.* 2007;21:784-787.
33. Fletcher IM, Jones B. The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. *J Strength Cond Res.* 2004;18:885-888.
34. Little T, Williams AG. Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. *J Strength Cond Res*. 2006;20:203-207.
35. Nelson AG, Kokkonen J, Arnall DA. Acute muscle stretching inhibits muscle strength endurance performance. *J Strength Cond Res*. 2005;19:338-343.
36. Church JB, Wiggins MS, Moode FM, Crist R. Effect of warm-up and flexibility treatments on vertical jump performance. *J Strength Cond Res*. 2001;15:332-336.
37. Shrier I. Does stretching improve performance? A systematic and critical review of the literature. *Clin J Sport Med.* 2004;14:267-273.
38. 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.
39. Wong P-L, Lau PWC, Mao DW, Wu YY, Behm DG, Wisløff U. Three days of static stretching within a warm-up does not affect repeated-sprint ability in youth soccer players. *J Strength Cond Res.* 2011;25:838-845.
40. Hopker JG, Coleman DA, Wiles JD, Galbraith A. Familiarisation and reliability of sprint test indices during laboratory and field assessment. *J Sports Sci Med.* 2009;8(4):528-532.
41. Hébert-Losier K, Platt S, Hopkins WG. Sources of variability in performance times at the world orienteering championships. *Med Sci Sports Exerc.* 2014;47(7):1523-1530.
42. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. *Eur J Appl Physiol Occup Physiol.* 1983;50(2):273-282.
43. Harman EA, Rosenstein MT, Frykman PN, Rosenstein RM. The effects of arms and countermovement on vertical jumping. *Med Sci Sports Exerc.* 1990;22(6):825-833.
44. Luhtanen P, Komi RV. Segmental contribution to forces in vertical jump. *Eur J Appl Physiol Occup Physiol.* 1978;38(3):181-188.
45. American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. *American College of Sports Medicine*. 8th ed. Philadelphia/Baltimore: Lippincott Williams & Wilkins; 2009.
46. Brandenburg J, Pitney WA, Luebbers PE, Veera A, Czajka A. Time course of changes in vertical-jumping ability after static stretching. *Int J Sports Physiol Perf.* 2007;2:170-181.
47. Behm DG, Chaouachi A. A review of the acute effects of static and dynamic stretching on performance. *Eur J Appl Physiol.* 2011;111:2633-2651.
48. Magnusson SP, Aagaard P, Nielson JJ. Passive energy return after repeated stretches of the hamstring

muscle-tendon unit. *Med Sci Sports Exerc.* 2000;32(6):1160-1164.

49. Madding SW, Wong JG, Hallum A, Medeiros J. Effect of duration of passive stretch on hip abduction range of motion. *J Orthop Sports Phys Ther.* 1987;8(8):409-416.
50. Granata KP, Wilson SE, Padua DA. Gender differences in active musculoskeletal stiffness. Part I. Quantification in controlled measurements of knee joint dynamics. *J Electromyog Kinesio.* 2002;12:119-126.
51. Floria P, Gomez-Landero LA, Harrison AJ. Variability in the application of force during the vertical jump in children and adults. *J Appl Biomech.* 2014;30(6):679-684.
52. Bishop D. Warm up II: Performance changes following active warm up and how to structure the warm up. *Sports Med.* 2003;33(7):483-498.
53. Hopkins WG, Hawley JA, Burke LM. Design and analysis of research on sport performance enhancement. *Med Sci Sports Exerc.* 1999;31(3):472-485.
54. Malcata RM, Hopkins WG. Variability of competitive performance of elite athletes: A systematic review. *Sports Med.* 2014 2014;44:1763-1774.