Apunts Med Esport. 2016;51(192):131–136

apunts
MEDICINA DE L'ESPORT
www.apunts/org

ORIGINAL ARTICLE

Vertical jump performance after passive static stretching of knee flexors muscles

Leonardo Mendes Leal de Souza[a], **Gabriel Andrade Paz**[a,b,*], **Isabella Luiza Eloi**[b], **Rodrigo Dias**[b], **Marianna de Freitas Maia**[a,b], **Humberto Miranda**[a], **Vicente Pinheiro Lima**[b]

[a] *School of Physical Education and Sports – Federal University of Rio de Janeiro, RJ, Brazil*
[b] *Biodynamic Laboratory of Exercise, Health, and Performance – Castelo Branco University, Rio de Janeiro, RJ, Brazil*

Received 1 March 2016; accepted 10 May 2016
Available online 15 July 2016

KEYWORDS
Performance;
Vertical jump;
Stretching;
Hamstring

Abstract
Objective: The purpose of this study was to investigate the acute effects of passive static stretching (PSS) applied on hamstring muscles on vertical jump height (VJ) performance.
Materials and methods: Ten men and 10 women with previous experience in resistance training were volunteers, and performed two protocols on non-consecutive days: traditional protocol (TRAD) including VJ without previous PSS, and a PSS protocol, with VJ immediately after stretching.
Results: Significant differences were observed in VJ performance with PSS (53.6 ± 8.5 cm) when compared to TRAD (47.9 ± 13.1 cm) for the women's group ($p = 0.021$). Significant differences were also observed in the men's group with PSS (58.4 ± 12.3) versus TRAD (51.4 ± 9.6) protocol ($p = 0.001$).
Conclusion: These results suggest that PSS applied only on hamstring muscles may have an acute effect on increasing the VJ performance for both men and women with previous experience in resistance training.

PALABRAS CLAVE
Desempeño;
Salto vertical;
Estiramiento;
Isquiotibiales

Rendimiento en el salto vertical después del estiramiento pasivo de los músculos flexores de la rodilla

Resumen
Objetivo: El objetivo de este estudio fue investigar el efecto agudo del estiramiento estático pasivo (ESP) aplicado en los músculos flexores de la rodilla en el rendimiento del salto vertical (SV).

* Corresponding author.
E-mail address: gabriel.andrade.paz@gmail.com (G.A. Paz).

http://dx.doi.org/10.1016/j.apunts.2016.05.005

Material y métodos: El estudio consistió en 10 hombres y 10 mujeres voluntarios con experiencia previa en el entrenamiento de fuerza (EF). Los sujetos realizaron 2 protocolos: EF sin ESP (TRAD) y SV inmediatamente después del estiramiento (ESP).
Resultados: Hubo una diferencia significativa en el rendimiento del salto vertical ESP (53,6 ± 8,5 cm) en comparación con el TRAD (47,9 ± 13,1 cm) en el grupo femenino. En comparación con los hombres también hubo diferencias significativas en el ESP (58,4 ± 12,3) y el TRAD (51,4 ± 12,3) ($p < 0,05$).
Conclusiones: Este estudio sugiere que el estiramiento estático pasivo aplicado solo en los flexores de la rodilla puede mejorar el rendimiento durante el SV para los hombres y mujeres entrenados.

Introduction

Stretching exercises are commonly performed by apparently healthy people and athletes with the goal to increase or maintain joint range of motion, and improving athletic performance, respectively.[1,2] Moreover, it can be used as part of warming up exercise before sports activities[3] and rehabilitation programs.[4,5]

There are several types of flexibility training methods, such as the static stretching, which is used to reach the above-mentioned benefits.[3] Despite the advantages of stretching, there are several studies which have been indicated that performing stretching before resistance exercises can significantly reduce torque,[6,7] strength performance,[8,9] power output, and agility.[10]

Regardless the force production mechanism, muscle power is characterized by several tasks performed in sport fields. One of these movements commonly performed during sport training programs and muscle power assessment is the vertical jump (VJ). In relation to concurrent training between flexibility and muscle power, there is still no consensus about the effect of stretching before power training. Bradley et al.[11] observed a significant reduction in the VJ performance after passive static stretching (PSS) applied in quadriceps, hamstring, and ankle flexors muscles. However, Sandberg et al.[12] found significant improvement in the VJ performance after PSS applied in hip flexors and ankle dorsiflexors muscles when compared to a protocol without stretching. In addition, other studies have been noted that the chronic application of PSS does not seem to have a negative effect on VJ performance.[13,14]

Besides these controversial results, to date, there is a lack of evidences of the subsequent VJ performance followed by PSS only adopted for knee flexors (KF) muscles. The KF muscles have an important function during the VJ, because of it synergic role with the quadriceps and gastrocnemius muscles, which is considered responsible for improving the joint stabilization during knee flexion–extension, and also improving the elastic energy storage.[15] Additionally, KF plays an important role during jumping tasks in order to assists the anterior cruciate ligament stabilization and also avoid the anterior tibial displacement.[16]

Furthermore, evidences related with the potential effects of PSS implemented with the goal to improve the VJ performance, may help coaches and conditioning professionals during the prescription of power training for lower limb muscles. Therefore, the purpose of this study was to investigate the acute effect of PSS applied in KF muscles on the VJ performance of recreationally trained men and women. We hypotheses that lower volume of PSS applied in KF muscles may increasing the stretch-shortening cycle (i.e. elastic energy storage) during the eccentric phase, and consequently, improving the VJ performance.

Materials and methods

Participants

The study was comprised 10 male and 10 female volunteers with previous experience in resistance training. The follow inclusion criteria were adopted: (a) to practice resistance training (RT) for at least three years; (b) to perform jumping tasks and power training with a frequency of three times per week; (c) to perform stretching exercises at least three months. The exclusion criteria were: (a) to respond the PAR-Q questionnaire positively; (b) to present any previous osteomioarticular injuries or surgery in lower limb; (c) to use any ergogenic substance that could influence in the power performance.

All the participants signed a consent form and the study was duly approved by the Castelo Branco University Research Ethics Committee under No. 2012/056 protocol and it was in according to the guidelines of the National Health Council Resolution 466/12 of human experiments. The anthropometric measures (i.e., height and body mass) were measured on a digital scale Filizola TM (Beyond Technology), following the recommendations proposed by the *International Society for the Advancement of Kinanthropometry* (ISAK).

Procedures

Before each test session, a standard warm up was adopted. The warm up was applied during 10 min and consisted of jogging, short sprints, and small jumps.[17]

Figure 1 Passive static stretching protocol applied to the knee flexors muscles.

Experimental protocols

After the warm up, two experimental protocols were applied in two non-consecutive days with 48 h intervals in a crossover randomized design: (a) traditional protocol (TRAD) – the participants performed the VJ without prior PSS; (b) passive static stretching protocol (PSS) – the researchers applied PSS on the knee flexors immediately followed by the VJ performance.

Passive static stretching (PSS)

The PSS applied in the knee flexors was applied following the recommendations of Herda et al.[18] The subject was positioned lied down in a supine position, and then the evaluator conducted a flexion of one hip, keeping the knee fully extended until to reach a point of discomfort indicated by the participants. Then, the range of motion of the stretched leg was maintained for 30 s, while the opposite lower limb was kept in a rest position on the ground. The same procedure was performed three times alternating right and left legs (see Fig. 1). Due to the great variability of the participant's flexibility, was not possible to adopt a standard hip flexion angle to the stretch.

Vertical jump testing

Firstly, the subject took the standing position, keeping aside a graduated surface and the right shoulder flexion of 180° and elbow in extension to the brand was registered for the initial test. Secondly, the distal phalanx of the middle finger of each subject was covered with chalk to represent the highest point reached on the wall surface. Then, during the downward phase of the VJ, the subjects performed and hold the flexion of the hips and knees, while the pendulum motion of flexion, extension and hyperextension of the shoulders (see Fig. 2A). In the ascending phase, the extent of the ankle, knee and hip was carried out and, bending the shoulders in order to jump as high as possible, touching the middle finger in the graduated wall surface (see Fig. 2B). Throughout the test, it was not allowed to move his feet before the VJ and the subjects were instructed to perform a full knee extension during the aerial part of the jump. Three attempts were allowed adopting 2-min intervals between them. The greatest value in centimeters between the three attempts was recorded.

Statistical analyses

Statistical analysis was performed in SPSS version 20.0 software (Chicago, IL, USA). Statistical analysis was initially performed using the Shapiro–Wilk test of normality and homoscedasticity test (Bartlett criterion). All variables showed normal distribution and homoscedasticity. Descriptive statistics (mean and standard deviation (SD)) were computed and presented for each dependent variable. The intraclass correlation coefficient (ICC = (MSb − MSW)/[MSb + (k − 1) MSW), where MSb = mean-square between, MSw = mean-square within, and k = average group size, was calculated to determine the reproducibility of intersubject for each measure. Paired T test was used to determine significant differences among protocols. The effect size was also computed following the Rhea[19] recommendations. The value of $p \leq 0.05$ was adopted for all inferential analyses.

Results

The ICC for VJ measures range about 0.91 and 0.93 between both protocols. Table 1 presents the participant's characteristic as age, height, total body mass and body mass index. No differences were noted inter and intragroup for the anthropometric variables ($p \leq 0.05$).

The mean values and the standard deviation of the maximum height reached by the volunteers obtained in the VJ are presented in Table 2. In the men group, there was a significant increase in the VJ performance under PSS (13.6%) compared to TRAD protocol ($p = 0.001$). Similar results were noted under PSS (11.9%) compared to TRAD condition for women group ($p = 0.021$). The effect size was classified as small for both groups.

Discussion

The purpose of the current study was to investigate the acute effect of PSS applied in KF muscles on VJ performance between men and women with previous RT experience. The main finding of the current study was the significant increasing in the VJ performance after PSS applied on hamstring muscle compared to the protocol without muscle stretching in both men and women groups. This finding suggests that PSS with lower volume applied only in the KF muscles can improve the VJ performance.

The VJ is considered a multi-joint movement and involves several muscle groups; other muscles besides the knee extensors, such as hip extensors and plantar flexors are also involved directly in its execution. In this sense, Sandberg et al.[12] verified the involvement of these other muscles in the VJ performance. Through the application of PSS on hip flexors and ankle extensors, muscles considered antagonists of the hip extensors and plantar flexors respectively, the authors observed a significant improvement in the performance of VJ after PSS protocol compared to the protocol without stretching. However, there are several muscles

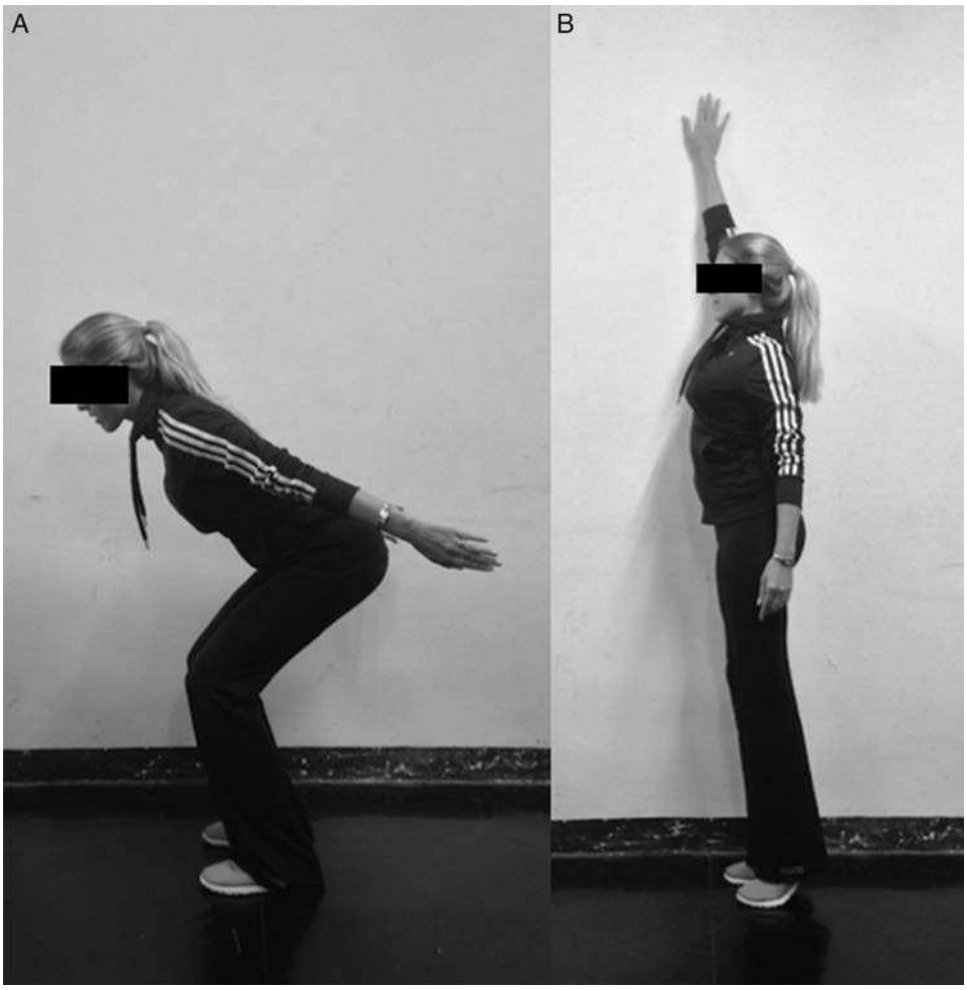

Figure 2 Vertical jump protocol. A.) The inicial position of the body before the jump. B.) The end phase of the jump were the participants touched the middle finger in the graduated wall surface. The participants were instructed to use their arms freely during the jump to allow touching the wall.

Table 1 Participants characteristics.

Groups	Age (years)	Height (cm)	Total body mass (kg)	BMI (kg/m^2)
Women ($n = 10$)	27 ± 3.8	168 ± 4.1	56.2 ± 4.5	24.7 ± 3.8
Men ($n = 10$)	27 ± 3.9	175 ± 6.9	75.2 ± 7.8	25.6 ± 4

BMI: body mass index.

Table 2 Vertical jump performance between experimental protocols under men and women groups.

Group	TRAD (cm)	PSS (cm)	Δ%	Effect size	p value
Women ($n = 10$)	47.9 ± 13.1	53.6 ± 8.5*	11.9%	0.43	0.021
Men ($n = 10$)	51.4 ± 9.6	58.4 ± 12.3*	13.6%	0.72	0.001

TRAD: VJ without static stretching; PSS: protocol of passive static stretching applied on knee flexors muscles before VJ; VJ: vertical jump.
* Statistically significant difference for TRAD condition ($p \leq 0.05$).

involved in the VJ task, and our results sought to present the responses induced by implementation of PSS applied only in the hamstring muscles and its influence in the VJ performance.

On the other hand, some studies have observed detrimental effects of PSS on strength and power performance when the stretching was applied in agonist muscles (i.e., target muscle) for both men and women.[6,20] Bradley et al.,[11]

investigated the effect of PSS, ballistic stretching and Proprioceptive neuromuscular facilitation (PNF) applied in the quadriceps, hamstrings and ankle extensors on the VJ performance immediately after stretching and during intervals of 5, 15, 30, 45 and 60 min. The authors found significant reduction in the performance of VJ up to 15 min after performing the PSS. Despite this controversial finding, some methodological differences, as the muscles involved in the stretching, can justify these distinct evidences. In Bradley et al.,[11] beyond the quadriceps muscle was involved, which is considered one of the agonists of the movement, a total of 10 min of five stretching exercises were performed, through two sets of 30 s for both legs, nevertheless in the current study was applied only three sets of 30 s only in the KF.

Additionally, the contrast between methodological variables of prescription, such as the volume and the duration of each stretching set, can influence the acute responses induced for a specific task. These influences was noted in previous studies, as demonstrated by Power et al.,[21] who observed reduction in torque and isometric strength of the knee extensors after PSS applied on the quadriceps, hamstrings and extensors of the ankle, during a protocol composed by three sets of 45 s with 15 s interval. However, the authors found no significant difference in the VJ performance. Moreover, Franco et al.[8] investigated the effect of different volumes of PSS and PNF applied on the triceps brachii before the performance of bench press exercise. The authors observed which one set of 40 s of PSS, resulted in a significant reduction in number of repetitions performed compared to the protocol without PSS. In this context, the studies which did not indicate deleterious effect of PSS on the VJ performance, often applied relatively low volume of PSS, similar to the procedures adopted in the current study. This evidence suggests which the volume, set, and the muscles involved in the stretching can be a determinant factor to induce a deleterious effect of the muscle power performance.

Biomechanical and neural aspects induced by stretching exercises which affect the VJ should be considered with the goal to better understand the possible strategies which could be implemented to improve its performance. Static stretching involves some mechanical adaptations within muscle, that alter properties of connective tissue elements, which results in a reduction in stiffness and consequently the passive tension.[22] These mechanisms involved, likely modify neuromuscular feedbacks that would result in a decrease of activation and muscle force-generating capacity.[23] Furthermore, although the major KF function as a joint stabilizer while performing knee flexion–extension,[15,16] it has only a secondary role to boost the body vertically,[24] thereby a possible reduction of its performance caused by stretching was enough to result in an increase performance of its antagonist, the knee extensors, as together with the gluteus maximum are the mainly responsible to produce angular acceleration and consequently reach higher heights during jumping.[25]

Considering that distinct levels of individual's flexibility might result different neuromuscular responses after stretching,[26] one of the limitations of the current study is that no baseline levels of flexibility were measured prior the experimental protocols. Additionally, future studies should consider the use of surface electromyograms to evaluate muscle activation pattern during VJ, and investigate the effect of different volumes of PSS on the KF and consequently its performance in the VJ. Thus, the comparison between different muscle groups in response to the application of PSS prior to muscle power tasks should be investigated. Nevertheless, the present study adopted procedures that could be easily implemented in sport fields, and it was verified that the PSS simply applied on the KF improves the VJ performance. In this context, considering that most athletes have been performing the VJ in their RT programs, these findings may help sport professionals during the prescription of stretching exercises and muscle power in the same training session with the goal to improve athletic performance and strength outcomes.

Conclusion

In conclusion, the results of this study suggest that PSS applied on the KF muscles with a total duration of 90 s (3 sets of 30 s) for each member is enough to significantly improve performance in VJ for both women and men with previous experience in RT. These findings indicate that lower volume of PSS can be applied only in the KF muscles prior to the VJ, thereby enhancing muscle performance during this specific movement and consequently optimizing the training outcomes. Therefore, future studies could investigate the effect of varying the volume of the PSS, muscles groups, and whether applied other types of stretching would result in an increasing in jumping performance.

Conflict of interest

Authors declare that they do not have any conflict of interests.

References

1. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position statement: quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc. 2011;43:1334–59.
2. Kokkonen J, Nelson AG, Eldredge C, Winchester JB. Chronic static stretching improves exercise performance. Med Sci Sports Exerc. 2007;39:1825–31.
3. Fradkin AJ, Gabbe BJ, Cameron PA. Does warming up prevent injury in sport? The evidence from randomized controlled trials. J Sci Med Sport. 2006;3:214–20.
4. Kamonseki DH, Gonçalves GA, Yi LC, Júnior IL. Effect of stretching with and without muscle strengthening exercises for the foot and hip in patients with plantar fasciitis: a randomized controlled single-blind clinical trial. Man Ther. 2015, http://dx.doi.org/10.1016/j.math.2015.10.006
5. Wilk KE, Hooks TR. Rehabilitation of the throwing athlete: where we are in 2014. Clin Sports Med. 2015;34:247–61.
6. Cramer JT, Housh TJ, Johnson GO, Miller JM, Coburn JW, Beck TW. Acute effects of static stretching on peak torque in women. J Strength Cond Res. 2004;18:236–41.
7. Costa PB, Ryan ED, Herda TJ, Walter AA, Defreitas JM, Stout JR, et al. Acute effects of static stretching on peak torque and the hamstrings-to-quadriceps conventional and functional ratios. Scand J Med Sci Sports. 2013;23:38–45.

8. Franco BL, Signorelli GR, Trajano GS, de Oliveira CG. Acute effects of different stretching exercises on muscular endurance. J Strength Cond Res. 2008;22:1832–7.
9. Nelson AG, Kokkonen J, Arnall DA. Acute muscle stretching inhibits muscle strength endurance performance. J Strength Cond Res. 2005;19:338–43.
10. McMillian DJ, Moore JH, Hatler BS, Taylor DC. Dynamic vs. static-stretching warm up: the effect on power and agility performance. J Strength Cond Res. 2006;20:492–9.
11. Bradley PS, Olsen PD, Portas MD. The effect of static, ballistic and proprioceptive neuromuscular facilitation stretching on vertical jump performance. J Strength Cond Res. 2007;21:223–6.
12. 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;26:1249–56.
13. Woolstenhulme MT, Griffiths CM, Woolstenhulme EM, Parcell AC. Ballistic stretching increases flexibility and acute vertical jump height when combined with basketball activity. J Strength Cond Res. 2006;20:799–803.
14. 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;22:25–31.
15. Escamilla R. Knee biomechanics of the dynamic squat exercise. Med Sci Sports Exerc. 2001;33:127–41.
16. Draganich LF, Jaeger RJ, Kralj AR. Coactivation of the hamstrings and quadriceps during extension of the knee. J Bone Joint Surg Am. 1989;71:1075–81.
17. Marcelino PB, Meirelles CLS, Melo SG, Soares YM. Vertical jump in young basketball players: estimation of the elastic energy/reflex potentiation and arm swing contribution. Rev Mackenzie Educ Fís Esporte. 2012;11:129–39.
18. Herda TJ, Cramer JT, Ryan ED, McHugh MP, Stout JR. Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. J Strength Cond Res. 2008;22:809–17.
19. Rhea M. Determining the magnitude of treatment effects in strength training research through the use of the effect size. J Strength Cond Res. 2004;18:918–20.
20. Marek SM, Cramer JT, Fincher AL, Massey LL, Dangelmaier SM, Purkayastha S, et al. Acute effects of static and proprioceptive neuromuscular facilitation stretching on muscle strength and power output. J Athl Train. 2005;40:94–103.
21. Power K, Behm D, Cahill F, Carroll M, Young W. An acute bout of static stretching: effects on force and jumping performance. Med Sci Sports Exerc. 2004;36:1389–96.
22. Morse CI, Degens H, Seynnes OR, Maganaris CN, Jones DA. The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. J Physiol. 2008;586:97–106.
23. Fowles JR, Sale DG, MacDougall JD. Reduced strength after passive stretch of the human plantar flexors. J Appl Physiol. 2000;89:1179–88.
24. Voigt M, Simonsen EB, Dyhre-Poulsen P, Klausen K. Mechanical and muscular factors influencing the performance in maximal vertical jumping after different prestretch loads. J Biomech. 1995;3:293–307.
25. Pandy MG, Zajac FE. Optimal muscular coordination strategies for jumping. J Biomech. 1991;24:1–10.
26. Blazevich AJ, Cannavan D, Waugh CM, Fath F, Miller SC, Kay AD. Neuromuscular factors influencing the maximum stretch limit of the human plantar flexors. J Appl Physiol. 2012;113:1446–55.