Original Article

A single bout of whole-body vibration improves hamstring flexibility in university athletes: A randomized controlled trial

JORGE OLIVARES-ARANCIBIA[1,2], PATRICIO SOLIS-URRA[2], FERNANDO RODRIGUEZ-RODRIGUEZ[2], ALEJANDRO SANTOS-LOZANO[3], JAVIER SANCHEZ-MARTINEZ[2], JUAN MARTÍN-HERNÁNDEZ[4], NATALIA ZURITA-CORVALÁN[2], KABIR SADARANGANI[5,6], CARLOS CRISTI-MONTERO[2]

[1]*Department of Physical Education, Faculty of Sciences of Sport and Physical Education, University of A Coruña, Spain*

[2]*IRyS Group, School of Physical Education, Pontifical Catholic University of Valparaíso, Chile*

[3]*i+HeALTH, Department of Health Sciences, European University Miguel de Cervantes, Valladolid, Spain*

[4]*Department of Health Sciences, European University Miguel de Cervantes, Valladolid, Spain*

[5]*School of Kinesiology, Faculty of Health Sciences, University of San Sebastián, Chile*

[6]*Department of Physical Education, Sport and Human Motricity, Faculty of Teacher Training and Education, Autonomous University of Madrid, Spain*

ABSTRACT

Hamstring muscle injuries are one of most frequent injuries in team sports. Whole-body vibration (WBV) has an important effect on flexibility that could prevent shortening of the hamstrings. To investigate both acute and residual effect of a single bout of WBV on hamstring flexibility in a group of university athletes from team sports 70 athletes (81% men, age 21 ± 1.9 years old) were separated into three groups; control group (CG; n=24), hamstring flexibility group without vibration (-V; n=23), and hamstring flexibility group with vibration (+V; n=23). Both -V and +V groups performed the same experimental protocol, composed of 6 sets of 30 seconds of passive hamstring flexibility over a vibration platform with both legs alternately (full-length 6 minutes; 3 minutes per leg). A high-magnitude vibration loading was applied only in +V group (40 Hz and 4 mm). Hamstring flexibility was evaluated through the Modified Sit and Reach (MSR) and Passive Straight Leg Raise (PSLR) test before (baseline), immediately after (acute effect), and after 72 h (residual effect)

Corresponding author. *IRyS Group, School of Physical Education, Pontificia Universidad Católica de Valparaíso, Chile.*
E-mail: carlos.cristi.montero@gmail.com
Submitted for publication December 2017
Accepted for publication May 2018
Published *in press* July 2018
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.14198/jhse.2018.134.06

intervention. Both experimental groups showed a significant improvement in flexibility compared to CG in all measures (p<0.05). No statistical differences were found between +V and –V, however, MSR, right PSLR, and left PSLR residual effect size (Cohen's d) were greater in +V. In conclusion, adding a WBV stimulus to flexibility training improves acute and residual hamstring flexibility in university athletes from team sports.
Keywords: Soccer; Vibration training; Injury prevention; Team sports; Stretching.

Cite this article as:

Olivares-Arancibia, J., Solis-Urra, P., Rodriguez-Rodriguez, F., Santos-Lozano, A., Sanchez-Martinez, J., Martín-Hernández, J., Zurita-Corvalán, N., Sadarangani, K., & Cristi-Montero, C. (2018). A single bout of whole-body vibration improves hamstring flexibility in university athletes: A randomized controlled trial. *Journal of Human Sport and Exercise*, *13*(4), 776-788. doi:https://doi.org/10.14198/jhse.2018.134.06

INTRODUCTION

Injuries to the hamstring muscle are frequent among individuals and within team sports (Edouard et al., 2016). This type of injury decreases range of motion in hip flexion and can negatively affect the pelvis and lumbar spine (Miñarro et al., 2008). Depending on the magnitude of damage, these injuries can restrain an athlete from competing for 14-18 days (Cross et al., 2015). In clinical sports screening, it is essential to assess and prevent shortening of the hamstrings (Cross et al., 2015; Witvrouw et al., 2003).

Several methods have shown positive effects on range of motion related to the hamstring muscle, both in athletes and physically active subjects (van den Tillaar, 2006; Fagnani et al., 2006). The most studied methods are passive, static and ballistic stretching techniques, proprioceptive neuromuscular facilitation (Dastmenash et al., 2010), and modified hold-relax stretching protocols (Spernoga et al., 2001).

Several experimental studies have suggested that whole or localized-body vibration generates a considerable increase in hamstrings flexibility (Van den Tillaar, 2006; Marshall & Wyon, 2012; Di Giminiani et al., 2010). A meta-analysis of 600 healthy young subjects showed that whole-body vibration (WBV) significantly improves flexibility when compared to the identical condition without vibration (Osawa & Oguma, 2013). Furthermore, an experimental study carried out in dancers determined the aforementioned additive effect of WBV could endure for over 48 hours (Marshall & Wyon, 2012). Therefore, WBV could possibly be used as a complementary training method to increase hamstring flexibility and reduce the prevalence of hamstring muscle injuries (Witvrouw et al., 2003; Henderson et al., 2010).

To date, there is a lack of studies that evaluate the residual effect of WBV on hamstring flexibility in team sports athletes. The aim of this study was to determine acute and residual effects (72 h) of WBV on hamstring flexibility in a group of athletes from university-level team sports.

MATERIALS AND METHODS

Experimental Design

The present study was designed according to CONSORT 2010 guidelines (Consolidated Standards of Reporting Trials), a checklist intended to improve the quality of reports of randomized controlled trials, consisting of 25 items (37 points total) (Schulz et al., 2011). In addition, this study uses recommendations of the International Society of Musculoskeletal and Neuronal Interactions (ISMNI) for reporting WBV intervention; including 13 factors of vibration platform and vibration parameters (i.e., intensity, amplitude, acceleration, body position, kind of exercise, etc.) (Rauch et al., 2010).

Participants

Sample size was determined according to changes in hamstring flexibility measured by MSR test given to a group of young physically active subjects, submitted to a control (Δ = 3.14 cm; SD = 2.11) or a bout of WBV (Δ = 5.30 cm; SD = 1.67) (Di Giminiani et al., 2010). Also, a loss rate of 20% was considered taking account the same reference study. Statistical power analysis indicated that at least 19 participants per group would yield adequate power (i.e., >80%) and α (i.e., <0.05), with a detectable variation of 2.16 cm (Δ between experimental – control group).

70 athletes (81% men; age 21.0 ± 1.9 yrs.; weight 68.4 ± 9.4 kg; height 170.5 ± 8.6 cm; fat 18.5 ± 6.2 %) from various team sports participated during September and October 2012. Subjects were separated into three groups randomly (https://www.randomizer.org) i) control group (CG; n=24), ii) flexibility group without

vibration (-V; n=23), and iii) flexibility group with vibrations (+V; n=23). The characteristics of each group are provided in Table 1. No statistical differences were found among groups in relation to their baseline characteristics.

Table 1. Characteristics of each participant's groups

Characteristic	CG (n= 24)	-V (n= 23)	+V (n= 23)	p-value
n (men/women)	19/5	19/4	19/4	---
Age (yrs)	21.1 ± 1.8	20.9 ± 1.8	21.0 ± 2.3	0.953
Weight (kg)	67.3 ± 10.4	67.7 ± 8.7	67.5 ± 9.1	0.982
Height (cm)	169.2 ± 9.2	171.5 ± 6.6	171.6 ± 9.4	0.619
Fat (%)	18.6 ± 6.2	19.0 ± 6.5	18.1 ± 6.3	0.827

Mean ± SD. CG: control group; -V: hamstring flexibility group without vibration; +V: hamstring flexibility group with vibration. Intergroup comparisons were assessed for significance by using one-way analysis of variance (ANOVA) with Bonferroni's post hoc test for multiple comparisons. A level of p<0.05 was accepted as statistically significant.

Inclusion criteria were: i) men and women aged 18-26 years old; ii) active participant of a university sports team organization (i.e., soccer, basketball, and volleyball); iii) training at least three times per week; iv) no history of hamstring injury in past 6 months. This last point was corroborated both through a personal interview and through a passive straight leg raise (PSLR) test. A PSLR angle >80º was considered a normal (Ayala et al., 2013). On the other hand, participants who missed any evaluation were excluded. This present study was conducted out according with the international deontological standard for research involving human subjects set forth in the declaration of Helsinki. All participants signed informed consent and were made aware of procedures and objectives. The Figure 1 shows phases of the randomized trial in a flow diagram.

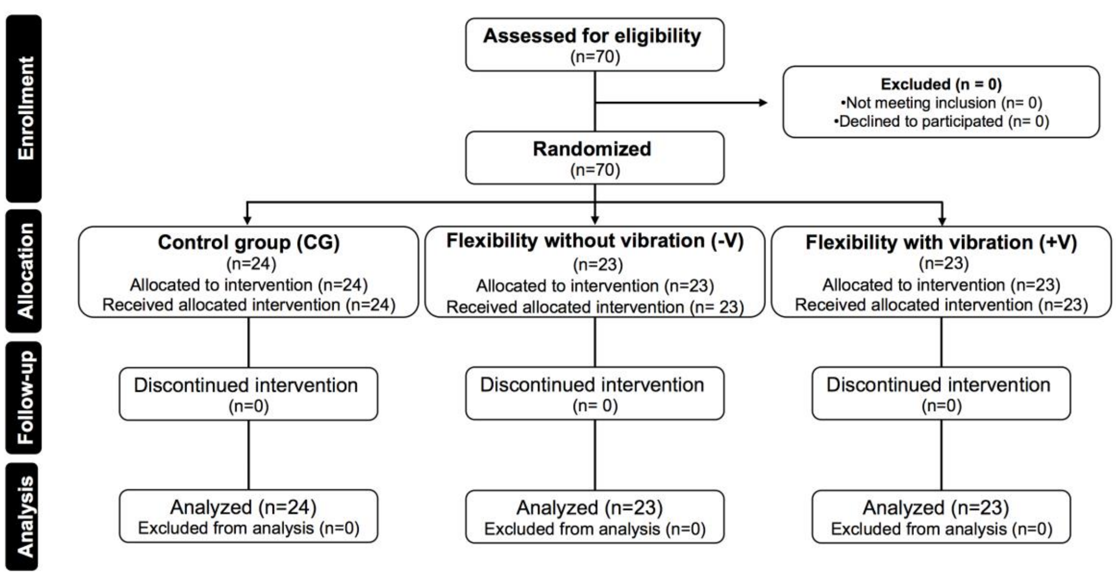

Figure 1. Flow diagram of progress through phases of randomized trial

Procedure

Each participant visited our physical activity laboratory three times (72 hour interval) in order for anthropometric measurements, hamstring flexibility evaluation and WBV experimental protocol (Figure 2). Participants did not present any physical complications during the experimental protocol.

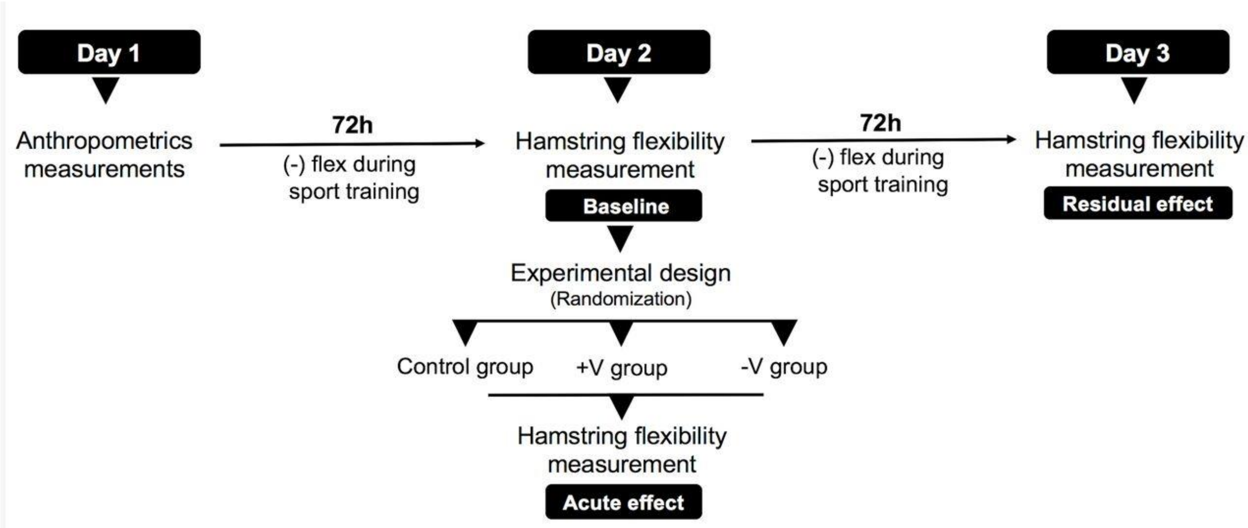

Figure 2. Procedure study

Day 1

On the first day, participants were familiarized with WBV experimental protocol**.** Anthropometric measurements were taken in the first hour of the morning (8:00 to 9:30 a.m.). Height (cm) was measured with a stadiometer (model 216, Seca, Germany). Weight (kg) and fat (%) have been evaluated by digital scale calibrated with a precision of 0.1 kg (electrical bioimpedance, model TBF-300A, Tanita, Japan). Participants were asked to fast overnight, not to exercise for at least 12 hours, and not to drink caffeine or alcoholic beverages for the previous 24 hours. Finally, the flexibility evaluation protocol and recommendations were explained the next evaluation day.

Day 2

Before and after WBV experimental protocol (baseline and acute effect, respectively), hamstring flexibility was evaluated by sit and reach modified (MSR) and PSLR test.

Day 3

72 hours after WBV experimental protocol, the MSR and PSLR test was evaluated again to determine residual effect.

Measurements

PSLR test

PSLR was measured by a universal goniometer with 1º increment (Whitehall Manufacturing, Model G300, USA) (Tsuji et al., 2014). All manual measurements were carried out by an expert examiner.

Legs of each participant were lifted passively into hip flexion by a second evaluator. The ankle was kept relaxed to minimize the influence of the gastrocnemius muscle. The endpoint for PSLR was determined by:

a) the examiner's perception of firm resistance, and b) palpable onset of pelvic rotation (Ayala et al., 2013). The test was performed twice, with a rest period of 10 seconds and the highest score was recorded.

Modified SR test

The American College of Sport Medicine evaluation protocol was used, (box 12-in. [30.5 cm] high). Before beginning the evaluation, participants were asked to slowly bend forward and try to touch their toes with legs, arms and hands fully extended. When finished, the participant sat on the floor with their heads, back and hips against the wall (90° at hip joint) and soles of the feet place against the edge of the box. In this position, participants were ordered to place one hand over the other, sliding along the measurement scale, with their head, back and hips remaining in contact with the wall. This distance established an initial point; later, participants performed a maximal trunk flexion with knees extended. The final result was distance in centimetres reached during maximal trunk flexion, taking as the initial reference the previously established. In order for this result to be valid, the patient had to maintain this position for at least 2 seconds. The test was performed twice with a rest period of 10 seconds, recording the farthest distance covered. This protocol mentioned has been used in prior studies (Ayala et al., 2012).

WBV experimental protocol

Both +V and -V groups performed the same experimental protocol (with or without vibration, respectively), composed of 6 sets of 30 seconds of passive hamstring flexibility over the vibration platform with both legs alternately (full-length 6 min; 3 min per leg). An instructor supervised constantly, timing each participant as they extended one leg to the platform (Ayala et al., 2013) and touching the tip of his foot with one hand with the other hand placed on the knee (Figure 3). The WBV experimental protocol using a vertical type vibration platform (Excel Pro, Fitvibe, Belgium) at intensity and amplitude of 40 Hz and 4 mm, respectively. Magnitude was estimated using the proposal equation of Kiiski equivalent to 25.8 g-force (Kiiski et al., 2008). In addition, this high-magnitude high-frequency loading has been used previously (Ghazalian et al., 2014). In relation to the control group; they should continue their sport training regularly. Moreover, no warm-up or stretching exercises were performed by the subjects prior to test measurements as methodological bias should have been present by increasing hamstring muscle extensibility (Ayala et al., 2013).

Statistical analysis

To determine baseline differences among groups, as well as the effect of vibration over time on each variable, we used one-way and two-way ANOVA 3x3 [three protocols (CG, +VI and –VI) three times each (baseline and, acute and residual effect)], respectively. Bonferroni post hoc testing was used in all pairwise comparisons when a significant result was found. Level of significance was set $p<0.05$. Statistical analysis with SPSS version 21. Also, effect size (ES) was calculated with Cohen´s *d* ([ES: mean post-intervention – mean pre-intervention] / pre-intervention standard deviation), where baseline values served for pre-intervention, and acute or residual values were post-intervention references. Strength of effect was assessed according to the following interpretation: trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (0.80 and greater) (Cohen, 1992).

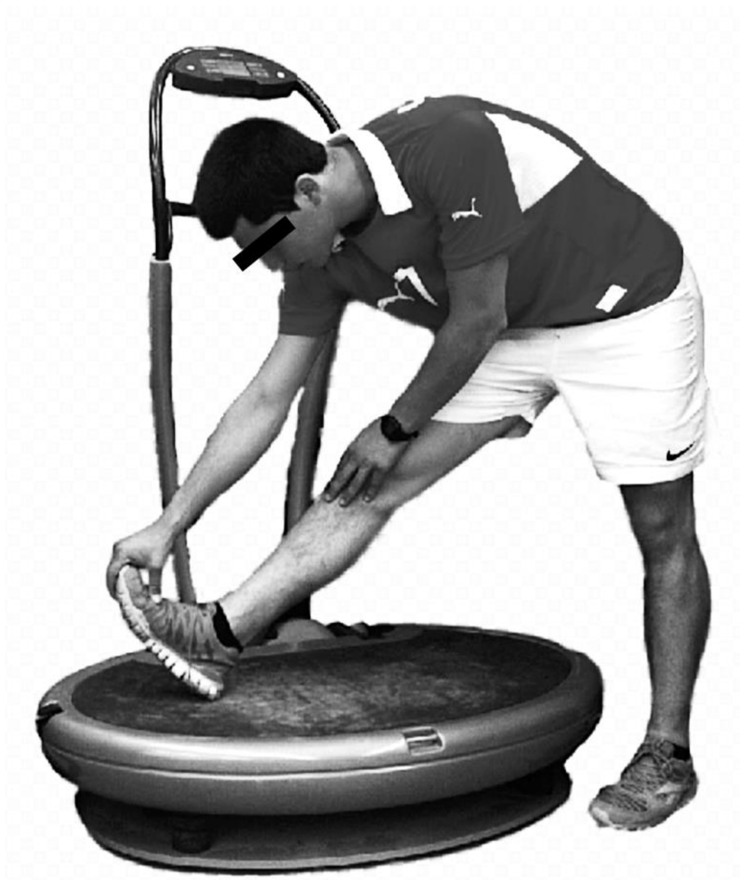

Figure 3. Hamstring flexibility and vibration position

RESULTS

Quality of randomized controlled trial and WBV experimental study

Regarding the CONSORT guide, this study met the requirements of 32 points, of the total 37. The following points were not achieved: 7b) explanation of any interim analyses and stopping guidelines, 11a) blinding, 11b) description of similarity of interventions, 23) registration number, and 24) full trial protocol.

According to ISMNI recommendation, this study obtained 11 points of the total 13. Only two points were not achieved, these are associated with: 7) skidding of feet was evaluated, and 8) changes of vibration settings.

Hamstring flexibility results

Non-differences were found among the 3 groups in regard to their initial values (baseline) in both MSR and PSLR test (right and left leg). table 2 shows the results of each test.

Sit and Reach modified

Both intervention groups (-V and +V) significantly increased hamstring flexibility compared with baseline ($p<0.05$). The +V group improved 5.7% more than –V, with greater ES (medium vs. small, respectively). In relation to the residual effect, both maintained the increased flexibility achieved 72 h prior, however, this improvement was 4.9% greater in +V than -V (Figure 4). The ES was reduced less in +V than in –V (0.51 to 0.38 and 0.28 to 0.17, respectively), and only +V managed to maintain a small ES (table 2).

Table 2. Acute and residual effect of WBV in hamstring flexibility

Test	Group	Mean ± SD			Mean difference (95% CI)		Δ% Change		Cohen´s d ES (95% CI)	
		Bas	Ac	Re	Bas vs. Ac	Bas vs. Re	Bas vs. Ac	Bas vs. Re	Bas vs. Ac	Bas vs. Re
MSR (cm)	CG	31.7±6.6	32.4±6.5	31.7±6.4	+0.74 (1.5 to 0.0)	-0.04 (0.8 to -0.7)	2.3	-0.1	0.11 (-0.45 to 0.66)	0.00 (-0.55 to 0.55)
	–VI	30.0±7.5	32.1±6.6	31.3±6.6	+2.13* (3.1 to 1.0)	+1.36* (2.3 to 0.3)	7.1	4.5	0.28 (-0.28 to 0.88)	0.17 (-0.39 to 0.76)
	+VI	31.2±7.8	35.2±7.7	34.2±7.5	+3.99* (4.9 to 3.0)	+2.92* (3.8 to 1.9)	12.8	9.4	0.51 (-0.08 to 1.12)	0.38 (-0.20 to 0.99)
PSLR Right leg (degree)	CG	89.1±8.6	91.3±9.0	88.5±8.1	+2.16 (4.5 to 0.22)	-0.64 (1.7 to 3.0)	2.4	-0.7	0.26 (-0.30 to 0.80)	0.07 (-0.62 to 0.48)
	–VI	84.1±6.9	90.9±8.7	88.0±7.3	+6.78* (9.3 to 4.2)	+3.91* (6.4 to 1.3)	8.1	4.6	0.99 (0.26 to 1.47)	0.57 (-0.904 to 1.13)
	+VI	79.8±10.3	87.8±10.2	87.6±9.3	+8.00* (10.7 to 5.3)	+7.72* (10.4 to 5.0)	10	9.7	0.78 (0.16 to 1.39)	0.76 (0.18 to 1.40)
PSLR Left leg (degree)	CG	89.7±9.6	91.9±8.5	89.0±7.9	+2.24 (4.9 to 0.4)	-0.64 (-2.0 to -3.3)	2.5	0.7	0.23 (-0.31 to 0.79)	0.07 (-0.63 to 0.47
	–VI	82.8±7.8	91.4±8.1	88.1±6.8	+8.60* (11.2 to 5.9)	+5.30* (7.9 to 2.6)	10.4	6.4	1.10 (0.46 to 1.7)	0.68 (0.12 to 1.32)
	+VI	77.8±12.0	88.2±11.1	87.3±8.8	+10.36* (13.7 to 6.9)	+9.45* (12.8 to 6.0)	13.3	12.1	0.87 (0.28 to 1.52)	0.79 (0.28 to 1.52)

*Bas: Baseline; Ac: Acute effect; Re: Residual effect. ES: Effect size. MSR= Sit and Reach modified; PSLR: passive Straight Leg Raise. CI: Confidence Interval 95%. *= Significant difference respect to Bas.*

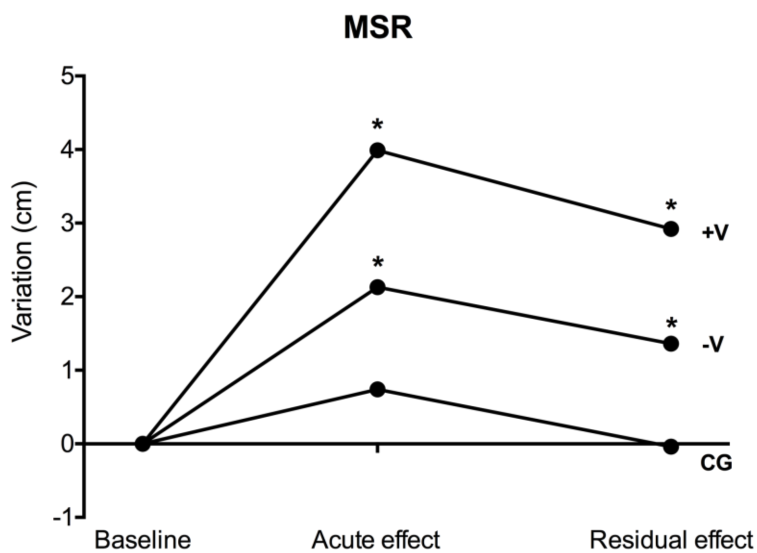

Figure 4. Variation in Sit and Reach modified test

Passive straight leg raise (Right leg)
Both intervention groups had a significant improvement ($p<0.05$) in respect to CG. Figure 5 shows the variation improvement of –V and +V with CG, both in acute and residual effect. Residual effect in both groups was maintained after 72 h, however, -V group reduced 3.5% for the PSLR test, while +V only 0.3%. The large ES of +V remained practically unaltered (0.78 to 0.76), but –V ES dropped significantly (0.99 to 0.57) (table 2).

Passive straight leg raise (Left leg)
Results for the left leg were very similar to the right. There was a significant enhance in –V and +V groups when compared to CG (7.9% and 10.5% in acute effect, respectively), but improvement of +V group was 2.9% above –V group (table 2). There was a large ES in both intervention groups in acute effect, however when the residual effect was analysed, a greater reduction was found in the –V group when compared to the +V (1.10 to 0.68) considering +V group (0.87 to 0.79) (Table 2).

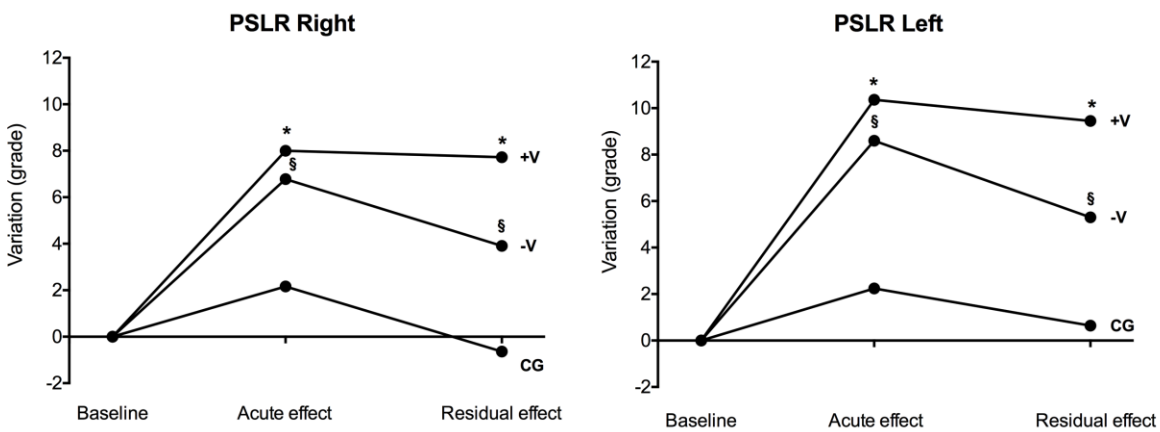

Figure 5. Passive straight leg raise (Right leg and left leg)

DISCUSSION

The aim of this study was to determine the acute and residual effect of WBV as a complement to training, in order to improve hamstring flexibility in university athletes from team sports. Findings indicate that adding a single bout of WBV to static stretching provides an important effect in maintaining hamstring flexibility 72 h post intervention. To our knowledge, this study is the first to evaluate the residual effect after 3 days, in athletes of team sports. Results are relevant in strategies to prevent shortening of the hamstrings.

To date, scientific evidence reflects improvements in hamstring flexibility using WBV in physically inactive subjects (Dastmenash et al., 2010; Ghazalian et al., 2014; Jacobs & Burns et al., 2009), physically active subjects (van den Tillaar, 2006; Feland et al., 2010), athletes (team and individual sports) (Hortobágyi et al., 2015) and others (Cristi et al., 2014). With respect to team sports, there is a scarcity of studies using WBV protocol to enhance flexibility of hamstring muscles. Two studies (in elite female field hockey players and sportswomen from various team sports) have shown significant improvement (8.2% and 13%, respectively) in hamstring flexibility after an acute bout of WBV (26 Hz, 6 mm) (Cochrane & Stannard, 2005) and a 8 week intervention (35 Hz, 4 mm) (Fagnani et al., 2006). Both studies generally conclude that improvement in flexibility is not only important for physical performance, but also for prevention of muscle-tendon injuries in team sports (Fagnani et al., 2006; Cochrane & Stannard, 2005).

Several studies examine the acute (Di Giminiani et al., 2010; Jacobs & Burns, 2009; Cochrane & Stannard, 2005) effect of WBV interventions over hamstring flexibility, however few studies evaluate residual effect (Di Giminiani et al., 2010; Cronin et al., 2008; Despina et al., 2014). On one hand, Cochrane & Stannard (2005) and Jacobs & Burns (2009) reported a significant improvement in SR test immediately post intervention (8.2% and 16.2%, respectively). Conversely, in regard to residual effect, most studies involve individual athletes. Cronin et al. (2008) and Despina et al. (2014) found significant differences after 10 and 15 min of WBV intervention in competitive athletes (2.0% and 3.6%, respectively). The present study reports an increase of 12.8% and 9.4%, in acute and residual effect, respectively. These results support the examination by Marshall & Wyon (2012) of residual effect at 48 hours post WBV training in female dancers. This study shows an improvement of 16.5%, however hamstring flexibility was measured through active range of motion and intervention lasted 4 weeks (2 sessions/week). Therefore, a single bout of WBV could improve the residual effect of hamstring flexibility, as well as longer-lasting intervention.

In order to achieve an increase in hamstring flexibility through WBV, it is paramount to consider the type of population (i.e., trained or untrained subjects) and magnitude of stimulus. In this way, Cardinale & Lim (2003) found different results when untrained subjects performed a high or low-intensity WBV intervention. These findings include a statistically significant increase in hamstring flexibility (13.5%) when applying 20 Hz, but not with 40 Hz (-3.3%). However, our study discovers an important increase using 40 Hz in athletes.

While literature has exposed that hamstring injuries are complicated and multifactorial (Draper et al., 1998), poor flexibility is one intrinsic related factor (Witvrouw et al., 2003; Henderson et al., 2010). Physiological mechanisms through which vibration training may improve flexibility such as neuromuscular factors, decrease in muscle stiffness, increase muscle elasticity and temperature (Feland et al., 2010), resulting from increased blood flow and increased pain threshold, are not entirely clear. While these principal mechanisms might be implicated in the increase of acute flexibility (Di Giminiani et al., 2010), no factors clearly justify the residual effect of WBV. Meanwhile, the lack of literature makes it difficult to draw conclusions related to residual effect. Draper et al. (Draper et al., 1998) showed that increase in temperature could be related to an overall increase of the applied load. This context would decrease viscous properties of tissue and increase length permanently, therefore complementing static stretching with WBV to generate a more enduring effect (Aminian et al., 2011).

Several studies have attempted to determine mechanisms to prevent hamstring injury or the risk factors associated with this injury (van Beijsterveldt et al., 2013; Brukner, 2015). Flexibility has been shown to be related with sport injury incidence (Witvrouw et al., 2003). Lack of, or asymmetries in leg flexibility have been known to play a secondary role in the hamstring strains of soccer players (van Beijsterveldt et al., 2013; Fousekis et al., 2011). Further, it has been demonstrated that increase in leg spring stiffness will enhance power, although excessive increment will begin to impair power production (Maloney et al., 2014) and increase the risk of injury. In this way, WBV has potential benefits in preventive and rehabilitation contexts. Similarly, Brukner (2015) recommends rehabilitation protocol be directed towards strength and flexibility, involving exercises with high loads and large muscle-tendon lengths. According to our results, WBV enhances flexibility and will decrease injuries due to stiffness. This complement to static stretching training could be applied three days prior to competition.

Our study presents limitations related to the design of research. This study design independently demonstrates important benefits of improving flexibility, though it is not possible to establish if this improvement will decrease rate of hamstring injuries in the long-term. It is necessary realize a longitudinal study and check rate of injury over time. Equipment used is another important consideration. Mechanic goniometers have low reliability when operated by inexperienced subjects, however the examiner used in our study has a high level of expertise. It is recommended to use an electronic goniometer to prevent bias in the results. Another possible limitation of this study could be the absence of intermediate measurements between post and 72h-post, as well as after 72h-post. These measurements could help trainers and athletes articulate the evolution of flexibility loss following an acute intervention, as well as ascertain whether increases in flexibility could last even longer than three days.

In conclusion, using a single bout of WBV to complement static stretching in traditional training has a potential effect on muscle flexibility in athletes from team sports. This is similar to static stretching alone, however, the effect of WBV could be maintained for at least three days. This study shows the valuable preventive role played by WBV in the shortening of the hamstring muscle. Trainers, physiotherapists and athletes could use a single bout of WBV three days prior to competition, to obtain important benefits to hamstring muscle flexibility.

REFERENCES

Aminian-Far, A., Hadian, M.-R., Olyaei, G., Talebian, S., & Bakhtiary, A. H. (2011). Whole-body vibration and the prevention and treatment of delayed-onset muscle soreness. Journal of Athletic Training, 46, 43–49. https://doi.org/10.4085/1062-6050-46.1.43

Ayala, F., Sainz de Baranda, P., Cejudo, A., & Santonja, F. (2012). Pruebas angulares de estimación de la flexibilidad isquiosural: análisis de la fiabilidad y validez. Revista Andaluza de Medicina Del Deporte, 5, 67–74. https://doi.org/10.1016/S1888-7546(12)70011-4

Ayala, F., Sainz de Baranda, P., Cejudo, A., & Santonja, F. (2013). Pruebas angulares de estimación de la flexibilidad isquiosural: descripción de los procedimientos exploratorios y valores de referencia. Revista Andaluza de Medicina Del Deporte, 6, 120–128. https://doi.org/10.1016/S1888-7546(13)70046-7

Ayala, F., Sainz de Baranda, P., De Ste Croix, M., & Santonja, F. (2013). Comparison of active stretching technique in males with normal and limited hamstring flexibility. Physical Therapy in Sport: Official Journal of the Association of Chartered Physiotherapists in Sports Medicine, 14, 98–104. https://doi.org/10.1016/j.ptsp.2012.03.013

Brukner, P. (2015). Hamstring injuries: prevention and treatment-an update. British Journal of Sports Medicine, 49, 1241–1244. https://doi.org/10.1136/bjsports-2014-094427

Cardinale, M., & Lim, J. (2003). Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 17, 621–624.

Cochrane, D. J., & Stannard, S. R. (2005). Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. British Journal of Sports Medicine, 39, 860–865. https://doi.org/10.1136/bjsm.2005.019950

Cohen, J. (1992). A power primer. Psychological Bulletin, 112, 155–159. https://doi.org/10.1037/0033-2909.112.1.155

Cristi, C., Collado, P. S., Márquez, S., Garatachea, N., & Cuevas, M. J. (2014). Whole-body vibration training increases physical fitness measures without alteration of inflammatory markers in older adults. European Journal of Sport Science, 14, 611–619. https://doi.org/10.1080/17461391.2013.858370

Cronin, J., Nash, M., & Whatman, C. (2008). The acute effects of hamstring stretching and vibration on dynamic knee joint range of motion and jump performance. Physical Therapy in Sport: Official

Journal of the Association of Chartered Physiotherapists in Sports Medicine, 9, 89–96. https://doi.org/10.1016/j.ptsp.2008.01.003

Cross, K. M., Saliba, S. A., Conaway, M., Gurka, K. K., & Hertel, J. (2015). Days to Return to Participation After a Hamstrings Strain Among American Collegiate Soccer Players. Journal of Athletic Training, 50, 733–741. https://doi.org/10.4085/1052-6050-50.2.12

Dastmenash, S., Tillaar, R. V. D., Jacobs, P., Shafiee, G. H., & Shojaedin, S. S. (2010). The Effect of Whole Body Vibration, Pnf Training or a Combination of Both on Hamstrings Range of Motion. World Applied Sciences Journal, 11, 744–751.

Despina, T., George, D., George, T., Sotiris, P., Alessandra, D. C., George, K., Stavros, K. (2014). Short-term effect of whole-body vibration training on balance, flexibility and lower limb explosive strength in elite rhythmic gymnasts. Human Movement Science, 33, 149–158. https://doi.org/10.1016/j.humov.2013.07.023

Di Giminiani, R., Manno, R., Scrimaglio, R., Sementilli, G., & Tihanyi, J. (2010). Effects of individualized whole-body vibration on muscle flexibility and mechanical power. The Journal of Sports Medicine and Physical Fitness, 50, 139–151.

Draper, D. O., Anderson, C., Schulthies, S. S., & Ricard, M. D. (1998). Immediate and residual changes in dorsiflexion range of motion using an ultrasound heat and stretch routine. Journal of Athletic Training, 33, 141–144.

Edouard, P., Branco, P., & Alonso, J.-M. (2016). Muscle injury is the principal injury type and hamstring muscle injury is the first injury diagnosis during top-level international athletics championships between 2007 and 2015. British Journal of Sports Medicine, 50, 619–630. https://doi.org/10.1136/bjsports-2015-095559

Fagnani, F., Giombini, A., Di Cesare, A., Pigozzi, F., & Di Salvo, V. (2006). The effects of a whole-body vibration program on muscle performance and flexibility in female athletes. American Journal of Physical Medicine & Rehabilitation / Association of Academic Physiatrists, 85, 956–962. https://doi.org/10.1097/01.phm.0000247652.94486.92

Feland, J. B., Hawks, M., Hopkins, J. T., Hunter, I., Johnson, A. W., & Eggett, D. L. (2010). Whole body vibration as an adjunct to static stretching. International Journal of Sports Medicine, 31, 584–589. https://doi.org/10.1055/s-0030-1254084

Fousekis, K., Tsepis, E., Poulmedis, P., Athanasopoulos, S., & Vagenas, G. (2011). Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. British Journal of Sports Medicine, 45, 709–714. https://doi.org/10.1136/bjsm.2010.077560

Ghazalian, F., Hakemi, L., Pourkazemi, L., Akhoond, M., & Ahmadi, M. (2014). Effects of different amplitudes of whole body vibration training on performance. Sport Sciences for Health, 10, 35–40. https://doi.org/10.1007/s11332-014-0170-4

Henderson, G., Barnes, C. A., & Portas, M. D. (2010). Factors associated with increased propensity for hamstring injury in English Premier League soccer players. Journal of Science and Medicine in Sport / Sports Medicine Australia, 13, 397–402. https://doi.org/10.1016/j.jsams.2009.08.003

Hortobágyi, T., Lesinski, M., Fernandez-Del-Olmo, M., & Granacher, U. (2015). Small and inconsistent effects of whole body vibration on athletic performance: a systematic review and meta-analysis. European Journal of Applied Physiology, 115, 1605–1625. https://doi.org/10.1007/s00421-015-3194-9

Jacobs, P. L., & Burns, P. (2009). Acute enhancement of lower-extremity dynamic strength and flexibility with whole-body vibration. Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 23, 51–57. https://doi.org/10.1519/JSC.0b013e3181839f19

Kiiski, J., Heinonen, A., Järvinen, T. L., Kannus, P., & Sievänen, H. (2008). Transmission of vertical whole body vibration to the human body. Journal of Bone and Mineral Research: The Official Journal of the

American Society for Bone and Mineral Research, 23, 1318–1325. https://doi.org/10.1359/jbmr.080315
Maloney, S. J., Turner, A. N., & Fletcher, I. M. (2014). Ballistic exercise as a pre-activation stimulus: a review of the literature and practical applications. Sports Medicine (Auckland, N.Z.), 44, 1347–1359. https://doi.org/10.1007/s40279-014-0214-6
Marshall, L. C., & Wyon, M. A. (2012). The effect of whole-body vibration on jump height and active range of movement in female dancers. Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 26, 789–793. https://doi.org/10.1519/JSC.0b013e31822a5ce8
Miñarro, P. A. L., García, P. L. R., Lucas, J. L. Y., Cárceles, F. A., & Fiol, C. F. (2008). Validez de la posición del raquis lumbo-sacro en flexión como criterio de extensibilidad isquiosural en deportistas jóvenes. Archivos de Medicina Del Deporte.
Osawa, Y., & Oguma, Y. (2013). Effects of vibration on flexibility: a meta-analysis. Journal of Musculoskeletal & Neuronal Interactions, 13, 442–453.
Rauch, F., Sievanen, H., Boonen, S., Cardinale, M., Degens, H., Felsenberg, D., International Society of Musculoskeletal and Neuronal Interactions. (2010). Reporting whole-body vibration intervention studies: recommendations of the International Society of Musculoskeletal and Neuronal Interactions. Journal of Musculoskeletal & Neuronal Interactions, 10, 193–198.
Schulz, K. F., Altman, D. G., Moher, D., & CONSORT Group. (2011). CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. International Journal of Surgery (London, England), 9, 672–677. https://doi.org/10.1016/j.ijsu.2011.09.004
Spernoga, S. G., Uhl, T. L., Arnold, B. L., & Gansneder, B. M. (2001). Duration of Maintained Hamstring Flexibility After a One-Time, Modified Hold-Relax Stretching Protocol. Journal of Athletic Training, 36, 44–48.
Tsuji, T., Kitano, N., Tsunoda, K., Himori, E., Okura, T., & Tanaka, K. (2014). Short-term effects of whole-body vibration on functional mobility and flexibility in healthy, older adults: a randomized crossover study. Journal of Geriatric Physical Therapy (2001), 37, 58–64.
van Beijsterveldt, A. M. C., van de Port, I. G. L., Vereijken, A. J., & Backx, F. J. G. (2013). Risk factors for hamstring injuries in male soccer players: a systematic review of prospective studies. Scandinavian Journal of Medicine & Science in Sports, 23, 253–262. https://doi.org/10.1111/j.1600-0838.2012.01487.x
van den Tillaar, R. (2006). Will whole-body vibration training help increase the range of motion of the hamstrings? Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 20, 192–196.
Witvrouw, E., Danneels, L., Asselman, P., D'Have, T., & Cambier, D. (2003). Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. A prospective study. The American Journal of Sports Medicine, 31, 41–46. https://doi.org/10.1177/03635465030310011801

