©Journal of Sports Science and Medicine (2017) **16,** 239-246
http://www.jssm.org

Research article

Effects of High Velocity Elastic Band versus Heavy Resistance Training on Hamstring Strength, Activation, and Sprint Running Performance

Donatas Janusevicius [1], Audrius Snieckus [1]✉, Albertas Skurvydas [1], Viktoras Silinskas [1], Eugenijus Trinkunas [1], Joan Aureli Cadefau [2] and Sigitas Kamandulis [1]
[1] Institute of Sport Science and Innovations, Lithuanian Sports University, Kaunas, Lithuania
[2] Institut Nacional d'Educació Física, Barselona, Spain

Abstract

Hamstring muscle injuries occur during high-speed activities, which suggests that muscular strength at high velocities may be more important than maximal strength. This study examined hamstring adaptations to training for maximal strength and for strength at high velocities. Physically active men (n = 25; age, 23.0 ± 3.2 years) were randomly divided into: (1) a resistance training (RT, n = 8) group, which performed high-load, low-velocity concentric–eccentric hamstring contractions; (2) a resistance training concentric (RTC; n = 9) group, which performed high-load, low-velocity concentric-only hamstring contractions; and (3) a high-velocity elastic band training (HVT, n = 8) group, which performed low-load, high-velocity concentric–eccentric hamstring contractions. Pre- and posttraining tests included hamstring strength on a hamstring-curl apparatus, concentric knee extension–flexion at 60°/s, 240°/s, and 450°/s, eccentric knee flexion at 60°/s and 240°/s, hamstring and quadriceps coactivation, knee flexion and extension frequency in the prone position, and 30-m sprint running speed from a stationary start and with a running start. Knee flexor torque increased significantly by 21.1% ± 8.1% in the RTC group and 16.2% ± 4.2% in the RT group ($p < 0.05$ for both groups). Hamstring coactivation decreased significantly in both groups. In the HVT group, knee flexion and extension frequency increased by 17.8% ± 8.2%, concentric peak torque of the knee flexors at 450°/s increased by 31.0% ± 12.0%, hamstring coactivation decreased, and running performance over 30 m improved ($p < 0.05$ for all parameters). These findings suggest that resistance training at high velocities is superior to traditional heavy resistance training for increasing knee flexor strength at high velocities, movement frequency, and sprint running performance. These findings also indicate that traditional training approaches are effective for increasing knee flexor strength and reducing knee extensor coactivation, but this outcome is limited to low and moderate speeds.

Key words: Hamstring muscles, muscle strength, high velocity, resistance training, running, torque.

Introduction

Hamstring muscle strength training is often used to increase and balance lower body power in both professional and recreational sports (Herman et al., 2009; Holcomb et al., 2007; Monajati et al., 2016). Competitors benefit from power enhancement in activities that involve sprinting and jumping (Kamandulis et al., 2012; McBride et al., 2002). Unfortunately, power sports are also associated with a high incidence rate of hamstring muscle strain-type injuries (Ekstrand et al., 2016; Freckleton and Pizzari, 2013; Mendiguchia et al., 2012). Hamstring muscles serve as a brake on the knee extension force generated by the quadriceps muscles, and strength imbalance between these muscle groups during concentric and/or eccentric actions may increase the risk for hamstring injury (Croisier, 2004; Yeung et al., 2009).

Epidemiological studies have showed that hamstring injuries alone account for 6–29% of all injuries reported in athletes who compete in Australian Rules football, rugby union, football, basketball, cricket, and track sprinting (Alonso et al., 2012; Bourne et al., 2015; Brooks et al., 2006; Croisier, 2004; Engebretsen et al., 2013; Meeuwisse et al., 2003; Orchard et al., 2002; Woods et al., 2004). The risk for reinjury remains elevated for at least 1 year, and the recurrence of the injury usually causes more serious consequences (Gabbe et al., 2006; Hägglund et al., 2006; Warren et al., 2010). Askling et al., (2012) distinguished two main hamstring injury types. One type occurs at high muscle action speed (e.g., sprinting) when the long head of the biceps femoris is the most loaded and vulnerable muscle. The second type occurs when the biceps femoris muscle is stretched (e.g., a high kick, decelerating while sliding), in which the semimembranosus–tendon connection is the most loaded tissue. The first (sprinting) type of injury appears to be more severe than the slow stretched type and requires a longer time to return to athletic activities (Opar et al., 2012). Biomechanical and kinematic studies have demonstrated that the biceps femoris is subject to the highest levels of muscle–tendon unit stretch throughout the crucial terminal swing phase in high-speed running (Schache et al., 2013; Schache et al., 2012), throughout the takeoff in jumping, and during kicking; this muscle accounts for 80% of hamstring injuries (Chumanov et al., 2011; Opar et al., 2012). The biceps femoris muscle is usually injured at high speed when it is activated by a greater force than it can tolerate, especially at a longer-than-optimal length (Askling et al., 2007; Schache et al., 2010).

Despite the increasing use of trauma-prevention programs in the past 20–30 years, the number of hamstring muscle injuries remains high and may even be increasing (Ekstrand et al., 2016). This trend suggests a need for different methods to reduce the risk of hamstring injury. Resistance training involving concentric and especially eccentric movements is considered to be important for reducing hamstring weakness and preventing musculoskeletal disorders (Al Attar et al., 2017; Douglas et al.,

Received: 15 January 2017 / Accepted: 22 March 2017 / Published (online): 01 June 2017

2017; Guex and Millet, 2013; Malliaropoulos et al., 2012; Mendez-Villanueva et al., 2016; van der Horst et al., 2015). Positive morphological, architectural and functional hamstring adaptations have been found after maximal eccentric knee training on isokinetic dynamometer (Guex et al., 2016), concentric-eccentric resistance training on weight machines (Potier et al., 2009, Franchi et al., 2014), as well as Nordic hamstring exercise training in recreationally active individuals (Bourne et al., 2017) and athletes (Mjølsnes et al., 2004; Schache et al., 2012). However, these strategies target the development of maximal strength but neglect the fact that most injuries occur during high-speed activities, which suggests that having sufficient strength at high movement velocity may be more important than maximal strength.

Training to increase strength at high movement velocities has gained much smaller attention in the literature. It should be noted that many of the studies used low resistance workloads performed as fast as possible, where movement velocity, however, was still low compared with that required in real sports settings (Mazani et al., 2017; Ramírez et al., 2015). Elastic bands may be used to create resistance to perform movements throughout the range of motion with a velocity and force generation dynamics close to those attained in sports activities as throwing, jumping or sprinting. Therefore, the purpose of the present study was to examine the effects of training for maximal strength and for strength at high velocities on hamstring adaptations. We hypothesized that light resistance training at high movement velocity using an elastic band would reduce the injury risk and increase greater overall hamstring muscle power compared with heavy resistance training. For the risk estimation, we have used classical risk indicators such as hamstring and quadriceps absolute strength, strength ratio, activation, and coactivation.

Methods

Subjects

Physically active male students (n = 25; age, 23.0 ± 3.2 years; height, 1.85 ± 0.05 m; weight, 84.2 ± 7.5 kg) of Sports Sciences Faculty were randomly divided into one of three groups. (1) The resistance training (RT, n = 8) group performed high-load and low-velocity hamstring concentric–eccentric actions. (2) The resistance training concentric (RTC; n = 9) group performed high-load and low-velocity concentric-only hamstring action. (3) The high-velocity elastic band training (HVT, n = 8) group performed low-load and high-velocity concentric–eccentric action. After randomization, the 3 groups did not differ significantly in age, body weight and height. Subjects were involved in recreational activities as jogging, swimming or sports games at a frequency of 1 to 3 times per week while they were encouraged to avoid such activities during the study. Exclusion criterion was a regular plyometric or resistance training performed ≥3 times per week within the last 6 months. The regional ethics committee approved the study. Written informed consent was obtained from each participant.

Procedure

Testing was performed 1 week before and 3–4 days after the training period. On the day of testing, age, body height (to the nearest 0.1 cm, Martin, GPM instrument, Siber Hegner, Switzerland), and body mass (to the nearest 0.1 kg, TBF-300 Body Composition Analyzer, Tanita, Philpots Close, UK) were measured. Body mass index was calculated from the height and body mass values. Height and mass were measured before the participants performed a standardized warm-up for 15 min, which comprised 10 min of bicycle pedaling and 5 min of dynamic stretching. After the warm-up, the concentric peak torque of the knee extensor and flexor muscles at velocities of 60°/s, 240°/s, and 450°/s, and eccentric isokinetic peak torque of the flexor muscles at velocities of 60°/s and 240°/s were tested using an isokinetic dynamometer (System 3; Biodex Medical Systems, Shirley, NY, USA). During muscle testing, electromyographic activity of the rectus femoris and the long head of the biceps femoris muscles was assessed using an MP150 system (Biopac Systems, Inc., Goleta, CA, USA). On the next day, participants performed a standardized warm-up for 20 min comprising 10 min of slow jogging, 5 min of dynamic stretching, and 5 min of running drills. They then completed four runs of 30 m, with 5 min of recovery between: two from a stationary starting position and two after a run-up as a measure of speed after a flying start. Participants were then randomly assigned into one of the three groups and performed only the test specific for each group for hamstring muscle strength (RT and RTC) or knee flexion and extension frequency (HVT). All testing procedures were repeated in the same order after the training program. Study was partly blinded as training, testing and analysis of the data were performed by different researchers unaware of the subject's group.

Dynamometry

An isokinetic dynamometer (System 3; Biodex Medical Systems) was used to measure concentric and eccentric isokinetic and isometric peak torque of the knee extensor and flexor muscles. The participants were strapped with a double shoulder seat belt to stabilize the upper body. The distal ends of the thigh and shank were strapped to the seat and the dynamometer arm, respectively. The rotational axis of the strength-testing machine was aligned with the knee joint axis. The subjects performed three maximal actions at angular velocities of 60°/s, 240°/s, and 450°/s in the concentric mode and at 60°/s and 240°/s in the eccentric mode. Peak torques was measured at every angular velocity and mode of action. For more accurate data analyses, we have exported sampled data from isokinetic system into the text file format (these data were original and not filtered). Then the data were imported into Microsoft Excel where artefacts were manually deleted and windowing for load range was made. In the exported text file three synchronized time series were present i.e. torque, angle and movement velocity. Sampling rate was 100 Hz. The angle of peak torque development was calculated at the highest torque reached at each speed of concentric angular velocity. Concentric hamstrings-concentric quadriceps and functional eccentric hamstrings-concentric quadriceps ratios were calculated using peak torque values. Each of the angular velocities and the concentric and eccentric measurements were separated by a rest of at least 2 min to prevent the development of fatigue. The best trial of three for each test was used for further analysis. Intraclass correlation coefficient for peak torque varied from 0.81 to 0.95 depending on exercise mode and velocity.

Electromyography

Electromyographic activity was assessed in the rectus femoris and the long head of the biceps femoris muscles (Hermens et al., 2000). An MP150 system (Biopac Systems, Inc.) was used to record the electromyogram (EMG). Two self-adhesive disposable Ag–AgCl electrodes (10-mm diameter, Ceracarta, Forlì (FC), Italy) were placed over the hamstring and quadriceps muscles with a 20-mm interelectrode distance, and the ground electrode was positioned on the knee. The skin at the electrode sites was shaved and cleaned with alcohol wipes. After securing the electrodes, a quality check was performed to ensure EMG signal validity. A raw EMG was acquired with a sampling frequency of 1000 Hz and was filtered using analogue high-pass (10 Hz) and low-pass (500 Hz) filters. The EMG signals were analyzed using Acknowledge software (Biopac Systems, Inc.). Coactivation of the rectus femoris and biceps femoris was assessed using the root mean square (RMS) of the EMG signal. The analyzed EMG signal was around 200 ms for the peak for isometric actions and 60°/s concentric actions, 100 ms for 240°/s concentric and 60°/s eccentric actions, and 20 ms for 450°/s concentric and 240°/s eccentric actions. The values are expressed as a percentage of the EMG activity during maximal activity of the muscle (Kellis and Baltzopoulos, 1996). The antagonist EMG is expressed as a percentage of the EMG of the antagonist muscle during maximal isometric and concentric muscle actions. Intraclass correlation coefficient for the root mean square of the EMG signal varied from 0.66 to 0.84 depending on exercise mode and velocity.

Running time registration

To record the sprint times over 30 m, a Brower Timing System (Draper, UT, USA) was used with photo gates placed at 0 m, 10 m, and 30 m. Two trials were performed from the starting position, which was 70 cm from the first photo-sensing element, and two additional trials were performed from 25-m run up, all completed at maximum efforts. A recovery of about 5 min was allowed between each trial. The best result was used for analysis. Running time was measured with an accuracy of ± 1 ms according to the instrument's manual. High reliability was observed for these tests with the intraclass correlation coefficients above 0.95.

Hamstring muscle strength

One repetition maximum (RM) was measured for both legs simultaneously on the leg-curl machine (Atletas, Siauliai, Lithuania). The 1-RM values were obtained for concentric hamstring muscle action only. Intraclass correlation coefficient of hamstring muscle strength was 0.94.

Knee flexion and extension frequency

We used a Sony 25 Hz digital camera to record the knee flexion and extension movement frequency. Each participant in the HVT group was laid in a prone position on a mattress with the legs straight. Then knee flexions and extensions at the full range of motion were performed alternating the legs as in freestyle swimming action as quickly as possible for 4 s. The frequency of movements was counted from footage as number of repetitions per time. Intraclass correlation coefficient of knee flexion/extension frequency was 0.84.

Training program

The training program comprised 5 weeks of resistance training using concentric and eccentric actions (RT group), concentric-only actions (RTC group), or high-velocity elastic band training (HVT group). The warm-up procedure was the same for all groups: 15 min of slow jogging, 10 min of dynamic stretching, and 5 min of running drills at intensities of 70%, 80%, and 90% of maximum. Participants performed a total of 15 sessions over 5 weeks, three times per week on Mondays, Wednesdays, and Fridays, with ≥48 h between each session. Each single training session lasted for 1 h.

The content of each session was the same in terms of exercise intensity, duration, and rest intervals for a given training group (RT, RTC, and HVT). The RT and RTC training programs involved the same exercise: lying hamstring curl exercise with full range of motion progressing over the 5 weeks of training from four to six sets, from three to one repetition at 95–100% intensity. The RT group raised and lowered the weight, and the RTC group only raised the weight, which was then lowered by the researcher. The HVT program involved the lying prone hamstring curl exercise performed with TheraBand™ silver rubber bands at maximum velocity for 4 s with a full range of motion. The hamstring curl movements were filmed with a Sony 25 Hz Digital camera, and the number of movements was calculated. The subjects all started with a 1-m length. When the subject had increased the frequency by two movements, resistance was added by increasing the band length by 1 m (100% elongation) each time, and the subjects were required to reach the previous frequency. The subjects performed 4–6 sets with a 5-min rest interval between sets. TheraBand™ silver rubber provides 4.6 kg resistance at 100% elongation. Most subjects were able to reach 300% elongation during the training program.

Statistical analyses

The data are presented as the arithmetic mean ± SD. Before the analyses, the Kolmogorov–Smirnov test was used to check the normality of the data distribution. The effects of group (RT vs RTC vs HVT) and time (pretraining vs posttraining) on the measured variables were compared using a two-way general linear model repeated-measures ANOVA with appropriate Greenhouse–Geisser correction for sphericity as required. If a significant effect was found, a Tukey post hoc test was performed to locate the differences between means. Additionally, paired t-test was used to compare posttraining vs pretraining values of muscle strength at leg-curl machine and flexion/extension frequency in each group separately. For all statistical tests, differences were regarded as significant when $p < 0.05$. All of the analyses were performed using IBM SPSS Statistics (IBM Corp., Armonk, NY, USA).

Results

Hamstring muscle strength on the leg curl machine increased by 21.1 ± 8.1% in the RTC group and by 16.2 ± 4.2% in the RT group ($p < 0.05$ for both groups). Knee flexion and extension frequency in a prone position test increased by 17.8 ± 8.2% in the HVT group ($p < 0.05$).

Group by time interaction effect was found in sprint times over 10 to 30 m from starting position and 30-m from a flying start (improved 1.8 and 2.1%, respectively, in the HVT, $p < 0.05$, Figure 1). Sprint running speed did not increase after the training period in any of the heavy resistance intervention groups ($p > 0.05$).

The results demonstrated a significant group by time interaction effect for concentric knee flexion peak torque at 450°/s with a larger increase in HVT group compared with RTC group (increased by 31.0 in HVT, declined by 6.1% in RTC, $p < 0.05$, Table 1). At the same velocity, group by time interaction was found in concentric knee extension peak torque (increased by 22.1% in HVT, $p < 0.05$). Time window at 450°/s velocity for the knee flexion and extension was between 30 to 80 ms, and remained unchanged after training period. The concentric peak torque for the knee flexors at 60°/s and 240°/s increased significantly for all three groups ($p < 0.05$, time effect).

The main effect of time was significant for eccentric knee flexion peak torque at 60°/s with most improvement in RT group (from 199 ± 41 to 218 ± 27 N·m, $p < 0.05$) as well as at 240°/s with major increase in HVT group (from 182 ± 46 to 220 ± 22 N·m, $p < 0.05$). No significant interactions or main effects were found for ratios of concentric hamstrings-concentric quadriceps or eccentric hamstrings-concentric quadriceps peak torques ($p > 0.05$).

The larger decrease in HVT than RT and RTC for the knee extensors coactivation at 450°/s was indicated by group and time interaction effect ($p < 0.05$, Table 2). Similarly, there was a group by time interaction effect in coactivation of the knee flexors at 450°/s with the HVT increasing significantly over the RT and RTC ($p < 0.05$). Coactivation during knee extension at 60 and 240°/s decreased after training in all groups ($p < 0.05$, time effect).

A significant time by group interaction effect was demonstrated for knee flexion optimal angle at 450 °/s, with a larger increase in HVT group than RT or RTC group ($p < 0.05$, Table 3). The main effect of time was observed for knee flexion optimal angle at 60 and 240°/s ($p < 0.05$). However, knee extension optimal angle did not change significantly in any group ($p > 0.05$).

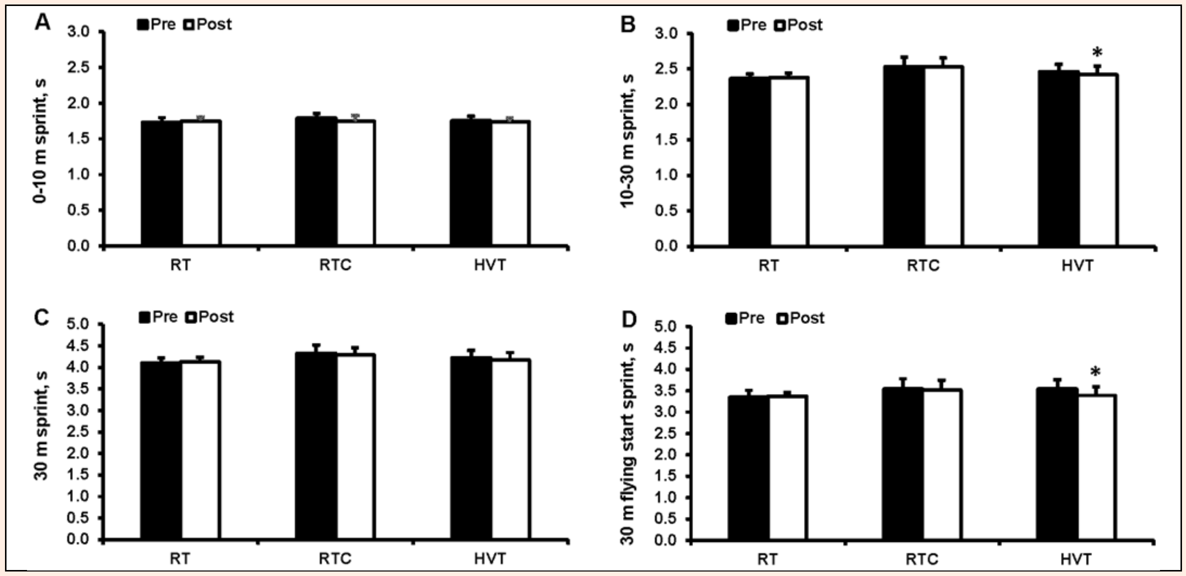

Figure 1. Sprint running performance at 0-10 m (A), 10-30 m (B), 30 m (C) and 30 meter flying start (D) after high load and low velocity concentric - eccentric (RT), high load and low velocity concentric (RTC) and low load and high velocity elastic band (HVT) hamstring training (mean ± SD). * $p < 0.05$ compared with baseline.

Table 1. Concentric peak torque (Nm) for knee flexion and knee extension. Data are average (±SD).

	Knee flexion						**Knee extension**					
	60°/s		**240°/s**		**450°/s**		**60°/s**		**240°/s**		**450°/s**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
RT	161 (31)	170 (32)	133 (36)	150 (28)	86 (27)	81 (20)	298 (36)	291 (46)	173 (23)	176 (23)	131 (19)	123 (18)
RTC	135 (29)	147 (27)	104 (32)	114 (18)	58 (27)	63 (25)	252 (39)	259 (33)	153 (31)	158 (28)	106 (22)	113 (23)
HVR	146 (23)	168 (33)	122 (24)	142 (27)	58 (37)	84 (34)	251 (35)	262 (17)	150 (37)	164 (20)	92 (25)	118 (26)
P	<.04 *		<.004 *		<.035 *; <.014 #		None		None		.025 *; .004 #	

RT, resistance training group, which performed high-load, low-velocity concentric–eccentric hamstring actions; RTC, resistance training concentric group, which performed high-load, low-velocity concentric-only hamstring actions; and HVT, high-velocity elastic band training. * Time, # Interaction

Table 2. **Co-activation index (%) for knee flexion and knee extension. Data are average (±SD).**

	Knee flexion						**Knee extension**					
	60°/s		**240°/s**		**450°/s**		**60°/s**		**240°/s**		**450°/s**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
RT	6.7 (7.4)	4.8 (1.0)	6.0 (3.1)	4.9 (1.5)	8.1 (5.0)	13.0 (8.3)	19.0 (9.7)	12.0 (3.4)	31.4 (12.8)	19.6 (5.2)	28.5 (21.2)	31.8 (7.8)
RTC	9.4 (8.8)	6.1 (2.8)	9.4 (6.6)	7.0 (2.5)	17.9 (11.6)	14.0 (5.9)	19.3 (14.9)	13.3 (8.2)	26.2 (12.5)	23.5 (14.9)	28.6 (19.1)	25.8 (15.2)
HVR	8.5 (5.9)	4.5 (1.2)	10.8 (9.1)	4.8 (1.5)	15.1 (13.8)	5.2 (1.9)	19.7 (5.5)	15.0 (7.6)	26.5 (13.3)	16.2 (6.0)	28.0 (15.2)	13.4 (3.4)
P	<.019 *		<.002 *; < .048#		<.006 *; <.018 #		< .045 *		< .27 *		.035 *; .001 #	

RT, resistance training group, which performed high-load, low-velocity concentric–eccentric hamstring actions; RTC, resistance training concentric group, which performed high-load, low-velocity concentric-only hamstring actions; and HVT, high-velocity elastic band training. * Time, # Interaction

Table 3. **Optimal angle (degree, 0° – full knee extension) for knee flexion and knee extension. Data are average (±SD).**

	Knee flexion						**Knee extension**					
	60°/s		**240°/s**		**450°/s**		**60°/s**		**240°/s**		**450°/s**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
RT	46 (5)	44 (4)	61 (3)	57 (4)	74 (2)	73 (2)	63 (2)	66 (4)	65 (5)	70 (7)	59 (4)	59 (4)
RTC	54 (4)	51 (6)	55 (6)	53 (4)	80 (3)	83 (8)	65 (6)	64 (6)	75 (9)	76 (10)	59 (5)	59 (4)
HVR	52 (9)	50 (7)	60 (12)	55 (9)	80 (8)	76 (8)	67 (6)	66 (7)	77 (9)	77 (11)	62 (6)	61 (5)
P	<.029 *		<.004 *		<.011 #		None		None		None	

RT, resistance training group, which performed high-load, low-velocity concentric–eccentric hamstring actions; RTC, resistance training concentric group, which performed high-load, low-velocity concentric-only hamstring actions; and HVT, high-velocity elastic band training. * Time, # Interaction

Discussion

The main finding of the present study is that elastic band training at high velocities was beneficial for increasing knee flexor strength at high velocities, movement frequency, and sprint running performance. More traditional heavy resistance training approaches are effective for increasing knee flexor strength and reducing knee extensor coactivation, but this outcome is limited to low and moderate speeds. Clear differences in training responses have been confirmed in the present study implying that high-resistance/low-speed strength training favors the development of maximal strength and muscle mass, whereas explosive training with lighter loads improves power (Cormie et al., 2010; Lamas et al., 2012; McBride et al., 2002; Smilios et al., 2013).

We used elastic bands for force enhancement because they provide light resistance that increases at the end of the range of motion. During resistance work with an elastic band, greater force is generated during each repetition during the last half of the concentric action and the first half of the eccentric action, and there is an enhanced transition from the concentric phase to the eccentric phase because of the decreasing overall band length on the return to the resting position. Such a training strategy was effective in increasing hamstring force, particularly at high velocities. This may reduce the risk of injury because muscle weakness is a risk factor for hamstring damage (Croisier, 2004; Opar et al., 2013; Yeung et al., 2009). By contrast, both training at high velocities and resistance training reduced muscle coactivation in the current study, which may predispose the knee joint to injury because adequate coactivation is needed to balance the differences in quadriceps and hamstring strength (Aagaard et al., 1998; 2000). Contrasting data were found for knee flexion optimal angle changes (velocity and training mode dependent), and neither the conventional nor the functional knee flexion–extension ratio increased significantly, although the knee flexion–extension ratio reduction in earlier studies has been shown to be an injury risk factor (Croisier et al., 2008; Fousekis et al., 2011; Kim and Hong, 2011; Myer et al., 2011). Therefore, whether resistance training at high movement velocity has a beneficial effect by reducing the injury risk remains unclear and requires further exploration.

In our study, resistance training at high movement velocity improved sprint performance. This effect was noticeable at maximal speed but not during the acceleration phase. This may be related to the increase in peak torque and the reduction in muscle coactivation at high velocities (450°/s) for both knee flexors and knee extensors. This suggests that resistance provided by the band's elasticity resulted in a significant increase in knee extensor and flexor power production, which was transferred effectively to running at maximal speed. This is consistent with findings that the high-velocity end of the force–velocity curve shows improvements after training with light but not with heavy loads (McBride et al., 2002; Smilios et al., 2013). Training with elastic bands has been shown to alter the force–velocity–power relationships during the squat (Israetel et al., 2010) and bench press (Baker and Newton, 2009). The mechanism responsible for this effect has been attributed mainly to neural adaptations because less muscle hypertrophy occurs after training with elastic bands than after typical heavy strength training (Van Cutsem et al., 1998). We observed reduced antagonist muscle activation in our study, which is consistent with neural adaptations and might also include changes in the temporal sequence or frequency of muscle activation (Ross and Leveritt, 2001).

It is interesting that, in our study, knee flexor force also improved after heavy resistance training but this change was insufficient to improve running performance. An increase in lower-body strength has been linked with improved running speed (Seitz et al., 2014). The present result suggests that heavy resistance training outcomes are limited to single-muscle (hamstring) strength and increased force only at low speed. The improvement in running time confirmed our expectation that elastic band training at high movement velocity would increase overall hamstring muscle power output more than would heavy resistance training. Further research could focus on synergistic effects of combined elastic band at high velocities and heavy resistance training.

There were clear effects of training specificity on the resistance training modes. Leg strength training on the machine increased maximum strength significantly but caused smaller changes in isokinetic muscle torque. This is consistent with the concept of exercise specificity; i.e., that force development differs between exercise modes. Muscles adapt specifically to the dominant velocity and force of contraction used during training. The strength developed by training on a weight machine does not necessarily transfer to an isokinetic movement. The athlete's work capacity depends on many factors, and adaptation of each factor and their sum requires specific exercises (Kraemer and Ratamess, 2004; Sale, 1988). Therefore, it was not surprising that muscle force at high velocity did not increase following the high-load resistance training. Maximum muscle force acquired by training with a very high resistance can interfere with the performance of movements at high velocity.

Our study has some limitations. It is difficult to estimate the contribution of the hamstring muscle to a complex task such as sprinting. However, the consistency of the results for different tests supports the appropriateness of the methods applied. Another limitation was that movement frequency test has not been carried out in heavy resistance training groups. The sample size was small, although it was of the usual size for most training studies (Campos et al., 2012; de Lira et al., 2013).

Conclusion

The results indicate that elastic band hamstring training at high velocities was effective for increasing force and decreasing coactivation of the hamstrings, particular at high muscle action velocities, improved knee flexion–extension movement frequency and these benefits were transferred positively to maximal running speed. These results provide strong support for this type of exercises in improving leg muscle power while benefits for hamstring injury risk reduction remain elusive and require further examination.

Acknowledgment

No financial assistance was provided for this study. Conflict of interests: none declared.

References

Aagaard, P., Simonsen, E.B., Andersen, J.L., Magnusson, S.P., Bojsen-Møller, F. and Dyhre-Poulsen, P. (2000) Antagonist muscle coactivation during isokinetic knee extension. *Scandinavian Journal of Medicine & Science in Sports* **10**(2), 58-67.

Aagaard, P., Simonsen, E.B., Magnusson, S.P., Larsson, B. and Dyhre-Poulsen, P. (1998) A new concept for isokinetic hamstring: quadriceps muscle strength ratio. *The American Journal of Sports Medicine* **26**(2), 231-237.

Al Attar, W.S.A., Soomro, N., Sinclair, P.J., Pappas, E. and Sanders, R.H. (2017) Effect of injury prevention programs that include the Nordic hamstring exercise on hamstring injury rates in soccer players: A systematic review and Meta-Analysis. *Sports Medicine* **47**(5), 907-916.

Alonso, J.-M., Edouard, P., Fischetto, G., Adams, B., Depiesse, F. and Mountjoy, M. (2012) Determination of future prevention strategies in elite track and field: analysis of Daegu 2011 IAAF Championships injuries and illnesses surveillance. *British Journal of Sports Medicine* **46**(7), 505-514.

Askling, C.M., Malliaropoulos, N. and Karlsson, J. (2012) High-speed running type or stretching-type of hamstring injuries makes a difference to treatment and prognosis. *British Journal of Sports Medicine* **46**(2), 86-87.

Askling, C.M., Tengvar, M., Saartok, T. and Thorstensson, A. (2007) Acute first-time hamstring strains during high-speed running: a longitudinal study including clinical and magnetic resonance imaging findings. *The American Journal of Sports Medicine* **35**(2), 197-206.

Baker, D.G., Newton, R.U. (2009) Effect of kinetically altering a repetition via the use of chain resistance on velocity during the bench press. *Journal of Strength and Conditioning Research*. **23**(7), 1941–1946.

Bourne, M.N., Duhig, S.J., Timmins, R.G., Williams, M.D., Opar, D.A., Al Najjar, A., Kerr, G.K. and Shield, A.J. (2017) Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: implications for injury prevention. *British Journal of Sports Medicine* **51**(5), 469-477.

Bourne, M.N., Opar, D.A., Williams, M.D. and Shield, A.J. (2015) Eccentric knee flexor strength and risk of hamstring injuries in rugby union: A prospective study. *The American Journal of Sports Medicine* **43**(11), 2663-2670.

Brooks, J.H.M., Fuller, C.W., Kemp, S.P.T., Reddin, D.B. (2006) Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *The American Journal of Sports Medicine*. **34**(8), 1297–1306.

Campos, F.A.D., Bertuzzi, R., Dourado, A.C., Santos, V.G.F. and Franchini, E. (2012) Energy demands in taekwondo athletes during combat simulation. *European Journal of Applied Physiology* **112**(4), 1221-1228.

Chumanov, E.S., Heiderscheit, B.C. and Thelen, D.G. (2011) Hamstring musculotendon dynamics during stance and swing phases of high-speed running. *Medicine and Science in Sports and Exercise* **43**(3), 525-532.

Cormie, P., McGuigan, M.R. and Newton, R.U. (2010) Adaptations in athletic performance after ballistic power versus strength training. *Medicine and Science in Sports and Exercise* **42**(8), 1582-1598.

Croisier, J.L. (2004) Factors associated with recurrent hamstring injuries. *Sports Medicine* **34**(10), 681-695.

Croisier, J.L., Ganteaume, S., Binet, J., Genty, M. and Ferret, J.M. (2008) Strength imbalances and prevention of hamstring injury in professional soccer players: A prospective study. *The American Journal of Sports Medicine* **36**(8), 1469-1475.

de Lira, C.A.B., Peixinho-Pena, L.F., Vancini, R.L., de Freitas Guina Fachina, R.J., de Almeida, A.A., Andrade, M.D.S. and da Silva, A.C. (2013) Heart rate response during a simulated Olympic boxing match is predominantly above ventilatory threshold 2: a cross sectional study. *Open Access Journal of Sports Medicine* **4**, 175-182.

Douglas, J., Pearson, S., Ross, A. and McGuigan, M. (2017) Chronic adaptations to eccentric training: A systematic review. *Sports Medicine* **47**(5), 917-941.

Ekstrand, J., Waldén, M. and Hägglund, M. (2016) Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. *British Journal of Sports Medicine* **50**(12), 731-737.

Engebretsen, L., Soligard, T., Steffen, K., Alonso, J.M., Aubry, M., Budgett, R., Dvorak, J., Jegathesan, M., Meeuwisse, W.H., Mountjoy, M., Palmer-Green, D., Vanhegan, I. and Renström, P.A. (2013) Sports injuries and illnesses during the London Summer Olympic Games 2012. *British Journal of Sports Medicine* **47**(7), 407-414.

Fousekis, K., Tsepis, E., Poulmedis, P., Athanasopoulos, S. and 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**(9), 709-714.

Franchi, M.V., Atherton, P.J., Reeves, N.D., Flück, M., Williams, J., Mitchell, W.K., Selby, A., Beltran Valls, R.M. and Narici, M.V. (2014) Architectural, functional and molecular responses to concentric and eccentric loading in human skeletal muscle. *Acta Physiologica* **210**(3), 642-654.

Freckleton, G. and Pizzari, T. (2013) Risk factors for hamstring muscle strain injury in sport: a systematic review and meta-analysis. *British Journal of Sports Medicine* **47**(6), 351-358.

Gabbe, B.J., Bennell, K.L. and Finch, C.F. (2006) Why are older Australian football players at greater risk of hamstring injury? *Journal of Science and Medicine in Sport* **9**(4), 327-333.

Guex, K., Degache, F., Morisod, C., Sailly, M. and Millet, G.P. (2016) Hamstring Architectural and Functional Adaptations Following Long vs. Short Muscle Length Eccentric Training. *Frontiers in Physiology* **3**(7), 340.

Guex, K. and Millet, G.P. (2013) Conceptual framework for strengthening exercises to prevent hamstring strains. *Sports Medicine* **43**(12), 1207-1215.

Hägglund, M., Waldén, M. and Ekstrand, J. (2006) Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. *British Journal of Sports Medicine* **40**(9), 767-772.

Herman, D.C., Oñate, J.A., Weinhold, P.S., Guskiewicz, K.M., Garrett, W.E., Yu, B. and Padua, D.A. (2009) The effects of feedback with and without strength training on lower extremity biomechanics. *The American Journal of Sports Medicine* **37**(7), 1301-1308.

Hermens, H.J., Freriks, B., Disselhorst-Klug, C. and Rau, G. (2000) Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography & Kinesiology* **10**(5), 361-374.

Holcomb, W.R., Rubley, M.D., Lee, H.J. and Guadagnoli, M.A. (2007) Effect of hamstring-emphasized resistance training on hamstring:quadriceps strength ratios. *Journal of Strength and Conditioning Research* **21**(1), 41-47.

Israetel, M.A., McBride, J.M., Nuzzo, J.L., Skinner, J.W., Dayne, A.M. (2010) Kinetic and kinematic differences between squats performed with and without elastic bands. *Journal of Strength and Conditioning Research* **24**(1), 190–194.

Kamandulis, S., Skurvydas, A., Brazaitis, M., Stanislovaitis, A., Duchateau, J. and Stanislovaitiene, J. (2012) Effect of a periodized power training program on the functional performances and contractile properties of the quadriceps in sprinters. *Research Quarterly for Exercise and Sport* **83**(4), 540-545.

Kellis, E. and Baltzopoulos, V. (1996) The effects of normalization method on antagonistic activity patterns during eccentric and concentric isokinetic knee extension and flexion. *Journal of Electromyography and Kinesiology* **6**(4), 235-245.

Kim, D. and Hong, J. (2011) Hamstring to quadriceps strength ratio and noncontact leg injuries: A prospective study during one season. *Isokinetics and Exercise Science* **19**(1), 1-6.

Kraemer, W.J., Ratamess, N.A. (2004) Fundamentals of resistance training: progression and exercise prescription. *Medicine and Science in Sports and Exercise*. **36**(4), 674–688.

Lamas, L., Ugrinowitsch, C., Rodacki, A., Pereira, G., Mattos, E.C.T., Kohn, A.F. and Tricoli, V. (2012) Effects of strength and power training on neuromuscular adaptations and jumping movement pattern and performance. *Journal of Strength and Conditioning Research* **26**(12), 3335-3344.

Malliaropoulos, N., Mendiguchia, J., Pehlivanidis, H., Papadopoulou, S., Valle, X., Malliaras, P. and Maffulli, N. (2012) Hamstring exercises for track and field athletes: injury and exercise biomechanics, and possible implications for exercise selection and primary prevention. *British Journal of Sports Medicine* **46**(12), 846-851.

Mazani, A.A., Hamdinia, M.R., Haghigi, A.H. and Hedayatpour, N. (2017) The effect of high speed strength training with heavy and low workloads on neuromuscular function and maximal concentric quadriceps strength. *The Journal of Sports Medicine and Physical Fitness*, Feb 14, Epub ahead of print.

McBride, J.M., Triplett-McBride, T., Davie, A. and Newton, R.U. (2002) The effect of heavy-vs. light-load jump squats on the development of strength, power, and speed. *The Journal of Strength & Conditioning Research* **16**(1), 75-82.

Meeuwisse, W.H., Sellmer, R. and Hagel, B.E. (2003) Rates and risks of injury during intercollegiate basketball. *The American Journal of Sports Medicine* **31**(3), 379-385.

Mendez-Villanueva, A., Suarez-Arrones, L., Rodas, G., Fernandez-Gonzalo, R., Tesch, P., Linnehan, R., Kreider, R. and Di Salvo, V. (2016) MRI-based regional muscle use during hamstring strengthening exercises in elite soccer players. *PloS One* **11**(9), e0161356.

Mendiguchia, J., Alentorn-Geli, E. and Brughelli, M. (2012) Hamstring strain injuries: are we heading in the right direction? *British Journal of Sports Medicine-*. **46**(2), 81-85.

Mjølsnes, R., Arnason, A., Østhagen, T., Raastad, T. and Bahr, R. (2004) A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scandinavian Journal of Medicine & Science in Sports* **14**(5), 311-317.

Monajati, A., Larumbe-Zabala, E., Goss-Sampson, M. and Naclerio, F. (2016) The effectiveness of injury prevention programs to modify risk factors for non-contact anterior cruciate ligament and hamstring injuries in uninjured team sports athletes: a systematic review. *PloS One* **11**(5), e0155272.

Myer, G.D., Ford, K.R., Khoury, J., Succop, P., Hewett, T.E. (2011) Biomechanics laboratory-based prediction algorithm to identify female athletes with high knee loads that increase risk of ACL injury. *British Journal of Sports Medicine*. **45**(4), 245–252.

Opar, D.A., Williams, M.D. and Shield, A.J. (2012) Hamstring strain injuries: factors that lead to injury and re-injury. *Sports Medicine* **42**(3), 209-226.

Opar, D.A., Williams, M.D., Timmins, R.G., Dear, N.M. and Shield, A.J. (2013) Knee flexor strength and bicep femoris electromyographical activity is lower in previously strained hamstrings. *Journal of Electromyography* & *Kinesiology* **23**(3), 696-703.

Orchard, J., James, T., Alcott, E., Carter, S. and Farhart, P. (2002) Injuries in Australian cricket at first class level 1995/1996 to 2000/2001. *British Journal of Sports Medicine* **36**(4), 270-274; discussion 275.

Potier, T.G., Alexander, C.M. and Seynnes, O.R. (2009) Effects of eccentric strength training on biceps femoris muscle architecture and knee joint range of movement. *European Journal* of *Applied Physiology* **105**(6), 939-944.

Ramírez, J.M., Núñez, V.M., Lancho, C., Poblador, M.S. and Lancho, J.L. (2015) Velocity-based training of lower limb to improve absolute and relative power outputs in concentric phase of half-squat in soccer players. *The Journal of Strength and Conditioning Research* **29**(11), 3084-3088.

Ross, A. and Leveritt, M. (2001) Long-term metabolic and skeletal muscle adaptations to short-sprint training: implications for sprint training and tapering. *Sports Medicine* **31**(15), 1063-1082.

Sale, D.G. (1988) Neural adaptation to resistance training. *Medicine and Science in Sports and Exercise* **20**(5 Suppl), S135-145.

Schache, A. (2012) Eccentric hamstring muscle training can prevent hamstring injuries in soccer players. *Journal of Physiotherapy* **58**(1), 58.

Schache, A.G., Dorn, T.W., Blanch, P.D., Brown, N.A.T. and Pandy, M.G. (2012) Mechanics of the human hamstring muscles during sprinting. *Medicine and Science in Sports and Exercise* **44**(4), 647-658.

Schache, A.G., Dorn, T.W., Wrigley, T.V., Brown, N.A.T. and Pandy, M.G. (2013) Stretch and activation of the human biarticular hamstrings across a range of running speeds. *European Journal of Applied Physiology* **113**(11), 2813-2828.

Schache, A.G., Kim, H.-J., Morgan, D.L. and Pandy, M.G. (2010) Hamstring muscle forces prior to and immediately following an acute sprinting-related muscle strain injury. *Gait & Posture* **32**(1), 136-140.

Seitz, L.B., Reyes, A., Tran, T.T., Saez de Villarreal, E. and Haff, G.G. (2014) Increases in lower-body strength transfer positively to sprint performance: a systematic review with meta-analysis. *Sports Medicine* **44**(12), 1693-1702.

Smilios, I., Sotiropoulos, K., Christou, M., Douda, H., Spaias, A. and Tokmakidis, S.P. (2013) Maximum power training load determination and its effects on load-power relationship, maximum strength, and vertical jump performance. *Journal of Strength and Conditioning Research* **27**(5), 1223-1233.

van Cutsem, M., Duchateau, J. and Hainaut, K. (1998) Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *The Journal of Physiology* **513 (Pt 1)**, 295-305.

van der Horst, N., Smits, D.-W., Petersen, J., Goedhart, E.A. and Backx, F.J.G. (2015) The preventive effect of the nordic hamstring exercise on hamstring injuries in amateur soccer players: a randomized controlled trial. *The American Journal of Sports Med-*

icine **43**(6), 1316-1323.

Warren, P., Gabbe, B.J., Schneider-Kolsky, M. and Bennell, K.L. (2010) Clinical predictors of time to return to competition and of recurrence following hamstring strain in elite Australian footballers. *British Journal of Sports Medicine* **44**(6), 415-419.

Woods, C., Hawkins, R.D., Maltby, S., Hulse, M., Thomas, A., Hodson, A., Football association medical research programme (2004) The football association medical research programme: an audit of injuries in professional football--analysis of hamstring injuries. *British Journal of Sports Medicine* **38**(1), 36-41.

Yeung, S.S., Suen, A.M.Y. and Yeung, E.W. (2009) A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. *British Journal of Sports Medicine* **43**(8), 589-594.

Key points

- Resistance training performed at high load and low velocities increases knee flexor strength and decreases hamstring coactivation, whereas does not change strength at high velocity.
- Elastic band training at high velocities increases strength and decreases hamstring coactivation, particularly at high muscle velocities.
- Elastic band hamstring training at high velocities has positive effects on both knee flexors and knee extensors, and these benefits transfer positively to sprint performance.

AUTHOR BIOGRAPHY

Donatas JANUSEVICIUS

Employment

PHD Student

Degree

MSc

Research interest

Exercise physiology, hamstring muscle injuries, strength and power training

E-mail: donatas.janusevicius@lsu.lt

Audrius SNIECKUS

Employment

Researcher, Institute of Sport Science and Innovations, Lithuanian Sports University, Kaunas, Lithuania

Degree

PhD

Research interest

Exercise induced muscle damage, Athletic training

E-mail: audrius.snieckus@lsu.lt

Albertas SKURVYDAS

Employment

Professor, Institute of Sport Science and Innovations, Lithuanian Sports University, Kaunas, Lithuania

Degree

Prof.

Research interest

Complex and dynamic adaptation in human motor system

E-mail: albertas.skurvydas @lsu.lt

Viktoras SILINSKAS

Employment

Researcher, Institute of Sport Science and Innovations, Lithuanian Sports University, Kaunas, Lithuania

Degree

PhD

Research interest

Athletic training

E-mail: viktoras.silinskas@lsu.lt

Eugenijus TRINKUNAS

Employment

Researcher, Institute of Sport Science and Innovations, Lithuanian Sports University, Kaunas, Lithuania

Degree

PhD

Research interest

Athletic training

E-mail: eugenijus.trinkunas@lsu.lt

Joan Aureli CADEFAU

Employment

Researcher at Institut Nacional d'Educació Física (INEFC), Barcelona, Spain

Degree

Prof.

Research interest

Muscle, exercise physiology, skeletal muscle, energy metabolism

E-mail: jcadefau@gencat.cat

Sigitas KAMANDULIS

Employment

Professor, Institute of Sport Science and Innovations, Lithuanian Sports University, Kaunas, Lithuania

Degree

Prof.

Research interest

Exercise induced muscle damage, fatigue, adaptation, athletic training

E-mail: sigitas.kamandulis@lsu.lt

✉ **Audrius Snieckus**

Institute of Sport Science and Innovations, Lithuanian Sports University, Kaunas, Lithuania