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

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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 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 (Crisier, 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 (Opal 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; Opal 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 (Asking 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.,
coactivation. Riceps absolute strength, strength ratio, activation, and used classical risk indicators such as hamstring and quad-
hamstring adaptations. We hypothesized that light re-
dynamics close to those attained in sports activities as
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 ve-
locities has gained much smaller attention in the litera-
ture. 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; Ramirez 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 re-
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 quad-
riceps 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 jogg-
ing, 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 regu-
lar 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
was comprised 10 min of bicycle pedaling and 5 min of dy-
namic stretching. After the warm-up, the concentric peak
torque of the knee extensor and flexor muscles at veloci-
ties 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, partic-
ipants 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 com-
pleted 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. Partici-
pants 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 train-
ing program. Study was partly blinded as training, testing
and analysis of the data were performed by different re-
searchers 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 rota-
tional 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 isoki-
netic 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 de-
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. Sam-
pling rate was 100 Hz. The angle of peak torque de-
velopment 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, p < 0.05). However, knee extension optimal angle 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).

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

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<th>Knee flexion</th>
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<td>60°/s</td>
<td>240°/s</td>
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<td>Pre</td>
<td>161 (31)</td>
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<td>Post</td>
<td>150 (28)</td>
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<td>&lt;.04 *</td>
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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 between 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 hamstrings 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 quadriiceps 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–power 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 Cutsen 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 syner-
gistic 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

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References


Two types of hamstring training

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.

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