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High-velocity elastic-band training improves hamstring muscle activation and strength in basketball players

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ABSTRACT

The aim of this study was use surface EMG activity to assess changes in co-activation of knee flexors and extensors muscle groups during elastic-band exercise after 5 weeks of high-velocity elastic-band training in basketball players. College male basketball players (n = 18) were randomly divided into one of two groups: (1) The elastic-band training group performed low-load and high-velocity - lying prone - hamstring curls training three times per week on top of their usual training; (2) The control group did not do any additional training. Pre- and post- training assessment included concentric knee extension and flexion at 60°/s and 240°/s, and the frequency of knee flexion and extension with elastic bands in the prone position. The EMG of the rectus femoris, semitendinosus muscles and the long head of the biceps femoris were assessed during these activities, and 30-m sprint running speed was measured from a stationary start and a running start. It was shown that high-velocity elastic-band training was 1) feasible, 2) increased movement velocity and 3) muscle strength, 4) altered neural control such that excessive lengthening of the hamstring muscle, and hence strain-injuries, may be prevented and 5) improved sprint performance in basketball players. In addition, these results suggest that high-velocity elastic-band training may be a tool to prevent hamstring strain-injuries in basketball players.

1. Introduction

Power sports are associated with a high incidence of hamstring muscle strain-type injuries (Ekstrand et al., 2016; Freckleton and Pizzari, 2013; Mendiguchia et al., 2012). Eighty percent of hamstring injuries occur in the long head of the biceps femoris (Chumanov et al., 2011; Opar et al., 2012) during high-speed actions (e.g., sprinting and jumping), especially at a longer-than-optimal length (Askling et al., 2007; Schache et al., 2010). The semimembranosus–tendon connection is more susceptible during activities such as high kick or decelerating actions (Askling et al., 2012).

Muscle weakness is an important risk factor for hamstring injury (Foreman et al., 2006). Resistance training using weight machines or own body weight, such as Nordic hamstring exercise, are the most prevalent training programmes to increase hamstring strength as a means to prevent such injuries (Bourne et al., 2018; Franchi et al., 2014; Mjølsnes et al., 2004; Potier et al., 2009; Schache et al., 2012). Yet, the success of these programmes is limited, as the incidence of hamstring muscle injuries remains high (Ekstrand et al., 2016). One of the causes may be that the applied exercises are mainly performed at low speed while most injuries occur during high-speed actions. It has hitherto not been investigated whether high-velocity exercises may provide a better protection against hamstring injuries.

The feasibility of high-velocity training modalities to increase hamstring strength is illustrated in non-athletes by the increase in knee extensor and knee flexor strength after elastic-band exercise training with a high frequency of knee flexion and extension (lying prone curls) (Janusevicius et al., 2017). In addition to increased strength, they observed a decrease in hamstring co-activation at high muscle contraction velocities that translated in better sprint performance. Part of these adaptations seem to be associated with neural adaptations, but it should be noted that neural adaptations were deduced from the EMG activity during isokinetic contractions, but not during knee flexion and extension during elastic-band exercise. It also important to note that the previous study (Janusevicius et al., 2017) was performed with non-athletes, who are likely to exhibit a stronger response to any exercise than athletes, and therefore benefits of such training for athletes remains to be established.

Therefore, the main objective of the current study was to determine changes in co-activation of knee flexors and extensors muscle groups during elastic-band exercise after 5 weeks of high-velocity elastic-band training in basketball players using surface EMG. We hypothesized that elastic-band training enhances muscle co-activation particularly during knee flexion and during transition from the flexion to the extension phases because elastic band provides greater resistance at the end of the hamstring concentric action, where more control of antagonistic muscle length is required (Israetel et al., 2010). The results will show not only whether elastic-band training is feasible in athletes, but also whether it results in changes that are conducive to prevent strain injuries, particularly during high-end performance. If the outcome of the study is positive, the next stage will be to study the efficacy of this programme to reduce the incidence of hamstring injuries in basketball players.

2. Methods

2.1. Subjects

Subjects were Lithuanian college division II male basketball players (mean ± standard deviation (SD)) (n = 18, age 21.5 ± 1.7 years, weight 83.5 ± 8.9 kg, height 192.5 ± 5.4 m) who had trained 5 to 10 years. They were randomly divided into one of two groups: (1) The elastic band training (EBT, n = 10) group performed low-load and high-velocity - lying prone - hamstring curls training on top of their usual training; (2) The control (CON, n = 8) group that did not do any extra training. The 2 groups did not differ significantly in age, body mass and height. The experiment was performed during the off-season period when basketball players were supposed to rest and they were encouraged to avoid additional intense activities during the study. Potential participants were excluded from the study if they had performed plyometric or resistance training during the last 2 months. The regional ethics committee approved the study. Written informed consent was obtained from each subject.

2.2. Training program

The training program consisted of 5 weeks of hamstring curl exercise performed with TheraBand™ silver rubber bands at maximum velocity for 4 s with full range of motion while lying prone. The subjects all started with a 1-m length. When the subject increased movement rate by one cycle per 4 s, resistance was added by increasing the band length by 1 m (100% elongation). The hamstring curls were filmed with a Sony 25-Hz

Digital camera to calculate the number of movements per s. The subjects performed 4–6 sets with a 5-min rest 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.

The warm-up consisted of 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.

2.3. Procedure

Testing was performed 1 week before and 3–4 days after the training period. On each 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. Then the participants performed a standardized warm-up for 15 min, which comprised 10 min of bicycle pedalling. After the warm-up, the concentric peak torque of the knee extensor and flexor muscles was measured at 60°/s and 240°/s using an isokinetic dynamometer (System 3; Biodex Medical Systems, Shirley, NY, USA). Electromyographic activity (EMG) of the rectus femoris (RF), semitendinosus muscles (ST) and the long head of the biceps femoris (BF) was assessed during dynamometry using an MP150 system (Biopac Systems, Inc., Goleta, CA, USA). The EMG of these muscles was also recorded during hamstring curls, while lying prone. 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 30-m runs, with 5 min rest between: two from a stationary starting position and two after a run-up as a measure of speed after a flying start. All assessment procedures were repeated in the same order after the training program. The study was partly blinded as training, testing and analysis were performed by different researchers, while only one researcher took part at each study stage.

2.4. Dynamometry

An isokinetic dynamometer (System 3; Biodex Medical Systems) was used to measure concentric 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 dynamometer was aligned with the knee joint axis. The subjects performed three maximal contractions at angular velocities of 60°/s and 240°/s. Sampling rate was 100 Hz. Each contraction was separated by a rest of at least 2 min to prevent the development of fatigue. The highest peak torque for each test was used for further analysis. Intra-class correlation coefficient of peak torque varied from 0.85 to 0.95 depending on exercise mode and velocity.

2.5. Electromyography

Electromyograms (EMG) were obtained with a MP150 system (Biopac Systems, Inc.). Three 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 inter-electrode distance, and the ground electrode was positioned on the knee. The skin at the electrode sites was shaved and cleaned with alcohol wipes. After positioning the electrodes, a quality check was performed to ensure EMG signal validity. The EMG was acquired with a 1000-Hz sampling frequency and filtered using analogue high-pass (10 Hz) and low-pass (500 Hz) filters. Muscle activation was assessed using the root mean square (RMS) of the EMG signal during flexion, the transition between flexion and extension (flexion-extension), extension, and the transition between extension and flexion (extension-flexion) during the hamstring curls with elastic bands (Fig 1). The RMS values were averaged during each phase and expressed as a percentage of the peak RMS during isokinetic knee flexion and extension (references to 100%). Intra-class correlation coefficient of the RMS of the EMG signal varied from 0.66 to 0.85 depending on exercise mode and velocity.

Figure 1 about here

2.6. 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 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 trials were completed at maximum velocity. A recovery of about 5 min was allowed between each trial. The best result was used for analysis. Running time registration accuracy is ± 1 ms according to the instrument's manual. High reliability was observed for these tests with the intraclass correlation coefficients above 0.95.

2.7. Lying prone hamstring curls

We used a Sony 25-Hz digital camera to record knee flexion and extension movement frequency. Each participant lay in a prone position on a mattress with the knees straight. He then lifted each foot, by bending the knee to bring the foot toward the buttocks. Both feet were tested at the same time. The movements were performed as quickly as possible for 4 s. The frequency and each curl phase duration were counted. The intra-class correlation coefficient of knee flexion and extension frequency was 0.85.

2.8. Statistical analyses

The data are presented as the arithmetic mean ± SD. The Shapiro–Wilks test showed that all data were normally distributed. Independent samples t-test was used to compare pre-training values between groups. The effects of group (EBT vs CON) and time (pre vs post training) 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. The same method was used to establish the effect of contraction phase (flexion, flexion-extension, extension and extension-flexion) or muscle group (RF, BF and ST) and time (pre vs post training) separately in each group. If a significant interaction was found, a one-way ANOVA was performed to locate the differences between means. Pearson's correlation coefficients were calculated to examine the relationship between variables in each group. Correlation magnitudes were: nearly perfect ($r > .9$), very large ($7 < r < .9$), large ($5 < r < .7$), moderate ($3 < r < 5$), small ($1 < r < 3$), or trivial ($r < 1$) according to Hopkins

(2000). For all statistical tests, differences were regarded as significant when $p<0.05$. All of the analyses were performed using SPSS 20.0 softwares (SPSS Inc., Chicago, Illinois, USA).

3. Results

Figure 2 about here

*Movement frequency and duration***.** Training increased hamstring curls from 9.0 ± 1.9 to 11.2 ± 1.4 per 4 s in the EBT group (by 25.7 %, $P<0.05$) and from 9.4 ± 1.3 to 9.7± 1.5 per 4 s in the CON group (by 2.6 %, $P > 0.05$). This was accompanied with a reduction in single curl duration in the EBT group ($P<0.05$, Fig 2), which was evident for each phase of the curl (Fig. 2). In the CON group, there were no significant main effects of duration for any parameter ($P > 0.05$ for all comparisons).

Figure 3 about here

Electromyography. There was no significant time x contraction phase interaction for RMS ($p > 0.05$ for both groups) indicating that changes over time were similar for each contraction phase. There was a significant time x group interaction for the normalized RMS, reflected by different changes in the EBT and CON group over time ($P < 0.05$, Fig. 3A & C). The RMS increased for BF and RF in EBT group ($P < 0.05$) but not for ST muscle whereas there were no significant alterations in RMS in the CON men (Fig. 3BC. In addition, the duration of EMG activity was significantly shorter for the ST and BF during flexion, and the RF, BF and ST during extension and flexion-extension ($P < 0.05$, Fig. 3B). The EMG duration was longer for the RF during flexion, and for the BF and ST during extension after training ($P < 0.05$, Fig 3 B), but no change was seen in the CON group (Fig. 3D). Hamstring curl frequency was related with the increase in antagonist muscle activation during flexion ($r = 0.48$ for RF muscle, $p < 0.05$) while other correlations were not significant.

Figure 4 about here

Muscle strength and running performance. Although there were significant main effects of time, group and contraction type ($P < 0.05$ for all cases, Fig. 4), the significant time x velocity interaction was reflected by a 21.5% increase at low and 25.8% at high velocities in EBT group ($P < 0.05$ for both velocities, Fig. 4), but not in the CON group.

Running performance over 30 m was improved by 1.6% from the starting position and by 2.1% from flying start ($p < 0.05$). Hamstring curls frequency was moderately related to running performance from starting position ($r = -0.43$, $P < 0.05$) but there was no significant relationship between performance and strength during flexion or extension ($r = 0.33$ and $r = 0.29$, $P > 0.05$). There was an inverse correlation between increase in flying start performance and increase in ST and RF activation duration during hamstring curl flexion phase ($r = -0.52$ and $r = -0.44$, $P < 0.05$).

Figure 4 about here

4. Discussion

The main observations of the present study are that high-velocity elastic-band hamstring training not only results in a slight improvement in sprint performance, but more importantly increases in knee flexion strength and altered hamstring muscle recruitment during flexion-extension cycles that likely prevent excessive lengthening of muscles during exercise, such as basketball playing. These benefits of high-velocity hamstring elastic-band training may well translate into a lower incidence of strain-type injuries in the hamstrings. Future studies will explore this further.

It was anticipated that the maximal velocity of movement increases markedly with elastic-band training in basketball players as demonstrated in non-athletes (Janusevicius et al., 2017). Although one might expect a less pronounced adaptation, as basketball players already regularly perform power and strength exercise (Montgomery et al., 2010), the magnitude of the training effect was similar to that seen in non-athletes (compared indirectly with (Janusevicius et al., 2017)). This similar adaptation may be related to the training being off-season, when training load and volume are low. It also important to note that elastic-band training was unfamiliar to both groups.

Neural adaptations have been proposed as the main mechanism for improved performance after high-speed training (DeWeese et al., 2015; Ross and Leveritt, 2001). In line with this we observed an increased activation of the BF and RF muscles (but not for ST). Such an enhanced activation of BF and RF may reciprocally protect the muscles against excessive length changes during explosive force production (first 50-75 ms), possibly as a result of increased motor unit recruitment in the hamstring muscles (Del Vecchio et al., 2019; Grazioli et al., 2019; Maffiuletti et al., 2016). Enhanced motor-unit firing at high frequencies and earlier recruitment of motor units has been previously demonstrated after explosive resistance training (Cormie et al., 2011; Folland and Williams, 2007; Griffin and Cafarelli, 2005). Contrary to our hypothesis, similar changes in muscle activation occur at different contraction phases even though loading was greater during knee flexion than during extension. Furthermore, the antagonist muscle activity duration remained the same or increased despite much shorter knee flexion or extension duration after training. While increased antagonist muscle activity does not stop movement, it has to switch-on earlier in case of high-speed movement. This indicates that not only activation magnitude but also task-specific improvements in cooperation between muscles is essential for high-speed performance

Our data are in agreement with other researchers who have found an increase in muscle strength after elastic band training (Colado et al., 2010; de Oliveira et al., 2017; Ghigiarelli et al., 2009; Lopes et al., 2019). We found that low-resistance/high-speed training particularly favours the development of torque at high velocities. It was less expected that both knee flexors and knee extensor torque increased. While knee extensors are less loaded during concentric contraction lying prone than when sitting, their activity is high during flexion deceleration in their antagonistic role. In this context it is interesting to note that the gains in force after training are not so much related to activation level, but rather to gains in the force generating capacity (Calatayud et al., 2015), that in addition is at a given activation level also higher during eccentric than concentric contractions.

The eccentric and concentric strength gains were more pronounced at high than low velocity contractions in both knee extensors and flexors and suggest altered force–velocity–power relationships (Israetel et al., 2010) that would favour sprint performance. Comparable results have been demonstrated for squat and bench press after training with elastic bands (Baker and Newton, 2008; Israetel et al., 2010) or sprint performance after resisted sled training (Alcaraz et al., 2018). However, rather than changes in the force-velocity-power relationship, the observed adaptations may be related more to neural adaptations, as indicated by the changes in recruitment during elastic-band exercise we observed, and the expected absence of muscle hypertrophy after training with elastic bands for a short period (Van Cutsem et al., 1998). Also other peripheral mechanisms may play a role, such as increased tendon stiffness that enhances effective force transmission (Kubo et al., 2007), but so far we are not aware of studies on the effect of elastic-band training on tendon properties.

It is of interest to note that an elastic band provides resistance in a way that makes it possible to initially reach high velocities, as at the start the contraction is almost unloaded. High velocities are considered essential for speed and power training (Behm and Sale, 1993; Cronin et al., 2002; Haff and Nimphius, 2012; Mazani et al., 2018). The programme also follows other power training recommendations, such as short exercise duration (4 s), sufficient rest between repetitions to avoid fatigue (3-5 min) and low training volume to avoid overall neuromuscular system fatigue (up to six repetitions three times per week). No concurrent training was applied during the study period. All these settings were important to achieve greater speed, force and power. We do not expect that this training will interfere with the usual training programmes in season, but this is something for further study.

Our observations do not enable us to conclude that elastic-band high-velocity training is an efficient approach to prevent hamstring injury incidence in athletes. However, muscle weakness (Bourne et al., 2018; Croisier, 2004; Opar et al., 2012; Shadle and Cacolice, 2017; Shield and Bourne, 2018; Yeung et al., 2009), low strength at high velocities and lack of muscle activation are associated with a high risk of hamstring injuries (Ekstrand et al., 2012). Therefore, the increased muscle strength and altered recruitment pattern of the hamstring muscles we observed are promising. We acknowledge that it has been reported that most of isokinetic knee flexor, knee extensor and hip extensor outputs at angular velocities ranging 30-300°/s had moderate or strong evidence for no association with future hamstring injury (Green et al., 2018). However, we believe that the combination of enhanced strength and altered neural control after high-velocity elastic-band training is a potential approach to reduce the incidence of hamstring injuries in basketball players.

The small sample size may be a study limitation but is rather typical for training studies (Kamandulis et al., 2012; Pliauga et al., 2018; Snieckus et al., 2013). Another limitation was that eccentric torque assessment has not been carried out during isokinetic measurements, which may have provided further insight in the changes induced by high-velocity elastic-band training. We also cannot exclude the possibility that some difficulties with test standardization, such as a controlled range of movement, during hamstring curls may have influenced some of the data. We think this will have a minor impact on the data as we made intra-individual comparisons.

5. Conclusions

The results of this study demonstrated that high-velocity elastic-band training was 1) feasible, 2) increased movement velocity, 3) muscle strength, 4) altered neural control such that excessive lengthening of hamstring muscles and hence strain-injuries may be prevented and 5) improved sprint performance in basketball players. These results are promising and suggest that high-velocity elastic-band training may be a tool to prevent hamstring strain-injuries in basketball players.

Conflict of interest

The authors have no conflicts of interest to report.

References

Alcaraz, P.E., Carlos-Vivas, J., Oponjuru, B.O., Martínez-Rodríguez, A., 2018. The Effectiveness of Resisted Sled Training (RST) for Sprint Performance: A Systematic Review and Meta-analysis. Sports Med. Auckl. NZ 48, 2143–2165. https://doi.org/10.1007/s40279-018-0947-8

Askling, C.M., Malliaropoulos, N., Karlsson, J., 2012. High-speed running type or stretching-type of hamstring injuries makes a difference to treatment and prognosis. Br. J. Sports Med. 46, 86–87. https://doi.org/10.1136/bjsports-2011-090534

Askling, C.M., Tengvar, M., Saartok, T., Thorstensson, A., 2007. Acute first-time hamstring strains during high-speed running: a longitudinal study including clinical and magnetic resonance imaging findings. Am. J. Sports Med. 35, 197–206. https://doi.org/10.1177/0363546506294679

Baker, D.G., Newton, R.U., 2008. Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. J. Strength Cond. Res. 22, 153–158. https://doi.org/10.1519/JSC.0b013e31815f9519

Behm, D.G., Sale, D.G., 1993. Intended rather than actual movement velocity determines velocity-specific training response. J. Appl. Physiol. Bethesda Md 1985 74, 359–368. https://doi.org/10.1152/jappl.1993.74.1.359

Bourne, M.N., Timmins, R.G., Opar, D.A., Pizzari, T., Ruddy, J.D., Sims, C., Williams, M.D., Shield, A.J., 2018. An Evidence-Based Framework for Strengthening Exercises to Prevent Hamstring Injury. Sports Med. Auckl. NZ 48, 251–267. https://doi.org/10.1007/s40279-017-0796-x

Calatayud, J., Borreani, S., Colado, J.C., Martin, F., Tella, V., Andersen, L.L., 2015. Bench press and push-up at comparable levels of muscle activity results in similar strength gains. J. Strength Cond. Res. 29, 246–253. https://doi.org/10.1519/JSC.0000000000000589

Chumanov, E.S., Heiderscheit, B.C., Thelen, D.G., 2011. Hamstring musculotendon dynamics during stance and swing phases of high-speed running. Med. Sci. Sports Exerc. 43, 525–532. https://doi.org/10.1249/MSS.0b013e3181f23fe8

Colado, J.C., Garcia-Masso, X., Pellicer, M., Alakhdar, Y., Benavent, J., Cabeza-Ruiz, R., 2010. A comparison of elastic tubing and isotonic resistance exercises. Int. J. Sports Med. 31, 810–817. https://doi.org/10.1055/s-0030-1262808

Cormie, P., McGuigan, M.R., Newton, R.U., 2011. Developing maximal neuromuscular power: Part 1--biological basis of maximal power production. Sports Med. Auckl. NZ 41, 17–38. https://doi.org/10.2165/11537690-000000000-00000

Croisier, J.-L., 2004. Factors associated with recurrent hamstring injuries. Sports Med. Auckl. NZ 34, 681–695. https://doi.org/10.2165/00007256-200434100-00005

Cronin, J.B., McNair, P.J., Marshall, R.N., 2002. Is velocity-specific strength training important in improving functional performance? J. Sports Med. Phys. Fitness 42, 267–273.

de Oliveira, P.A., Blasczyk, J.C., Souza Junior, G., Lagoa, K.F., Soares, M., de Oliveira, R.J., Filho, P.J.B.G., Carregaro, R.L., Martins, W.R., 2017. Effects of Elastic Resistance Exercise on Muscle Strength and Functional Performance in Healthy Adults: A Systematic Review and Meta-Analysis. J. Phys. Act. Health 14, 317–327. https://doi.org/10.1123/jpah.2016-0415

Del Vecchio, A., Negro, F., Holobar, A., Casolo, A., Folland, J.P., Felici, F., Farina, D., 2019. You are as fast as your motor neurons: speed of recruitment and maximal discharge of motor neurons determine the maximal rate of force development in humans. J. Physiol. 597, 2445–2456. https://doi.org/10.1113/JP277396

DeWeese, B.H., Hornsby, G., Stone, M., Stone, M.H., 2015. The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. J. Sport Health Sci. 4, 308–317. https://doi.org/10.1016/j.jshs.2015.07.003

Ekstrand, J., Healy, J.C., Waldén, M., Lee, J.C., English, B., Hägglund, M., 2012. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. Br. J. Sports Med. 46, 112–117. https://doi.org/10.1136/bjsports-2011-090155

Ekstrand, J., Waldén, M., 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. Br. J. Sports Med. 50, 731–737. https://doi.org/10.1136/bjsports-2015-095359

Folland, J.P., Williams, A.G., 2007. The adaptations to strength training : morphological and neurological contributions to increased strength. Sports Med. Auckl. NZ 37, 145–168. https://doi.org/10.2165/00007256-200737020-00004

Foreman, T.K., Addy, T., Baker, S., Burns, J., Hill, N., Madden, T., 2006. Prospective studies into the causation of hamstring injuries in sport: A systematic review. Phys. Ther. Sport 7, 101–109. https://doi.org/10.1016/j.ptsp.2006.02.001

Franchi, M.V., Atherton, P.J., Reeves, N.D., Flück, M., Williams, J., Mitchell, W.K., Selby, A., Beltran Valls, R.M., Narici, M.V., 2014. Architectural, functional and molecular responses to concentric and eccentric loading in human skeletal muscle. Acta Physiol. Oxf. Engl. 210, 642–654. https://doi.org/10.1111/apha.12225

Freckleton, G., Pizzari, T., 2013. Risk factors for hamstring muscle strain injury in sport: a systematic review and meta-analysis. Br. J. Sports Med. 47, 351–358. https://doi.org/10.1136/bjsports-2011-090664

Ghigiarelli, J.J., Nagle, E.F., Gross, F.L., Robertson, R.J., Irrgang, J.J., Myslinski, T., 2009. The effects of a 7-week heavy elastic band and weight chain program on upper-body strength and upper-body power in a sample of division 1-AA football players. J. Strength Cond. Res. 23, 756–764. https://doi.org/10.1519/JSC.0b013e3181a2b8a2

Grazioli, R., Lopez, P., Andersen, L.L., Machado, C.L.F., Pinto, M.D., Cadore, E.L., Pinto, R.S., 2019. Hamstring rate of torque development is more affected than maximal voluntary contraction after a professional soccer match. Eur. J. Sport Sci. 1–6. https://doi.org/10.1080/17461391.2019.1620863

Green, B., Bourne, M.N., Pizzari, T., 2018. Isokinetic strength assessment offers limited predictive validity for detecting risk of future hamstring strain in sport: a systematic review and meta-analysis. Br. J. Sports Med. 52, 329–336. https://doi.org/10.1136/bjsports-2017-098101

Griffin, L., Cafarelli, E., 2005. Resistance training: cortical, spinal, and motor unit adaptations. Can. J. Appl. Physiol. Rev. Can. Physiol. Appl. 30, 328–340.

Haff, G., Nimphius, S., 2012. Training Principles for Power. Strength Cond. J. 34, 2–12. https://doi.org/10.1519/SSC.0b013e31826db467

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. J. Strength Cond. Res. 24, 190–194. https://doi.org/10.1519/JSC.0b013e31819b7995

Janusevicius, D., Snieckus, A., Skurvydas, A., Silinskas, V., Trinkunas, E., Cadefau, J.A., Kamandulis, S., 2017. Effects of High Velocity Elastic Band versus Heavy Resistance Training on Hamstring Strength, Activation, and Sprint Running Performance. J. Sports Sci. Med. 16, 239–246.

Kamandulis, S., Skurvydas, A., Brazaitis, M., Stanislovaitis, A., Duchateau, J., Stanislovaitiene, J., 2012. Effect of a periodized power training program on the functional performances and contractile properties of the quadriceps in sprinters. Res. Q. Exerc. Sport 83, 540–545. https://doi.org/10.1080/02701367.2012.10599143

Kubo, K., Morimoto, M., Komuro, T., Yata, H., Tsunoda, N., Kanehisa, H., Fukunaga, T., 2007. Effects of plyometric and weight training on muscle-tendon complex and jump performance. Med. Sci. Sports Exerc. 39, 1801–1810. https://doi.org/10.1249/mss.0b013e31813e630a

Lopes, J.S.S., Machado, A.F., Micheletti, J.K., de Almeida, A.C., Cavina, A.P., Pastre, C.M., 2019. Effects of training with elastic resistance versus conventional resistance on muscular strength: A systematic review and meta-analysis. SAGE Open Med. 7, 2050312119831116. https://doi.org/10.1177/2050312119831116

Maffiuletti, N.A., Aagaard, P., Blazevich, A.J., Folland, J., Tillin, N., Duchateau, J., 2016. Rate of force development: physiological and methodological considerations. Eur. J. Appl. Physiol. 116, 1091–1116. https://doi.org/10.1007/s00421-016-3346-6

Mazani, A.A., Hamedinia, M.R., Haghighi, A.H., Hedayatpour, N., 2018. The effect of high speed strength training with heavy and low workloads on neuromuscular function and maximal concentric quadriceps strength. J. Sports Med. Phys. Fitness 58, 428–434. https://doi.org/10.23736/S0022-4707.17.06655-5

Mendiguchia, J., Alentorn-Geli, E., Brughelli, M., 2012. Hamstring strain injuries: are we heading in the right direction? Br. J. Sports Med. 46, 81–85. https://doi.org/10.1136/bjsm.2010.081695

Mjølsnes, R., Arnason, A., Østhagen, T., Raastad, T., Bahr, R., 2004. A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. Scand. J. Med. Sci. Sports 14, 311–317. https://doi.org/10.1046/j.1600-0838.2003.367.x

Montgomery, P.G., Pyne, D.B., Minahan, C.L., 2010. The physical and physiological demands of basketball training and competition. Int. J. Sports Physiol. Perform. 5, 75–86.

Opar, D.A., Williams, M.D., Shield, A.J., 2012. Hamstring strain injuries: factors that lead to injury and re-injury. Sports Med. Auckl. NZ 42, 209–226. https://doi.org/10.2165/11594800-000000000-00000

Pliauga, V., Lukonaitiene, I., Kamandulis, S., Skurvydas, A., Sakalauskas, R., Scanlan, A.T., Stanislovaitiene, J., Conte, D., 2018. The effect of block and traditional periodization training models on jump and sprint performance in collegiate basketball players. Biol. Sport 35, 373–382. https://doi.org/10.5114/biolsport.2018.78058

Potier, T.G., Alexander, C.M., Seynnes, O.R., 2009. Effects of eccentric strength training on biceps femoris muscle architecture and knee joint range of movement. Eur. J. Appl. Physiol. 105, 939–944. https://doi.org/10.1007/s00421-008-0980-7

Ross, A., Leveritt, M., 2001. Long-term metabolic and skeletal muscle adaptations to short-sprint training: implications for sprint training and tapering. Sports Med. Auckl. NZ 31, 1063–1082. https://doi.org/10.2165/00007256-200131150-00003

Schache, A.G., Dorn, T.W., Blanch, P.D., Brown, N.A.T., Pandy, M.G., 2012. Mechanics of the human hamstring muscles during sprinting. Med. Sci. Sports Exerc. 44, 647–658. https://doi.org/10.1249/MSS.0b013e318236a3d2

Schache, A.G., Kim, H.-J., Morgan, D.L., Pandy, M.G., 2010. Hamstring muscle forces prior to and immediately following an acute sprinting-related muscle strain injury. Gait Posture 32, 136–140. https://doi.org/10.1016/j.gaitpost.2010.03.006

Shadle, I.B., Cacolice, P.A., 2017. Eccentric Exercises Reduce Hamstring Strains in Elite Adult Male Soccer Players: A Critically Appraised Topic. J. Sport Rehabil. 26, 573–577. https://doi.org/10.1123/jsr.2015-0196

Shield, A.J., Bourne, M.N., 2018. Hamstring Injury Prevention Practices in Elite Sport: Evidence for Eccentric Strength vs. Lumbo-Pelvic Training. Sports Med. Auckl. NZ 48, 513–524. https://doi.org/10.1007/s40279-017-0819-7

Snieckus, A., Kamandulis, S., Venckūnas, T., Brazaitis, M., Volungevičius, G., Skurvydas, A., 2013. Concentrically trained cyclists are not more susceptible to eccentric exercise-induced muscle damage than are stretch-shortening exercise-trained runners. Eur. J. Appl. Physiol. 113, 621–628. https://doi.org/10.1007/s00421-012-2470-1

Van Cutsem, M., Duchateau, J., Hainaut, K., 1998. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. J. Physiol. 513 (Pt 1), 295–305. https://doi.org/10.1111/j.1469-7793.1998.295by.x

Yeung, S.S., Suen, A.M.Y., Yeung, E.W., 2009. A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. Br. J. Sports Med. 43, 589–594. https://doi.org/10.1136/bjsm.2008.056283

Figures captions

Fig. 1. Outline of EMG signal recording for rectus femoris (RF), long head of the biceps femoris (BF) and semitendinosus (ST) muscles during hamstring curls lying prone extension, extension-flexion, flexion and flexion-extension phases

Fig. 2. Duration of A) flexion, B) flexion-extension, C) extension and D) extension-flexion phases during hamstring curls lying prone in elastic band training (EBT) and control (CON) groups (average ± SD). ∗$P < 0.05$ compared to pre-exercise (Pre) value.

Fig. 3. (A, C) Root mean square (RMS) and (B, D) duration of the EMG signal changes for rectus femoris (RF), long head of the biceps femoris (BF) and semitendinosus (ST) muscles during hamstring curls lying prone in elastic band training (A, B) and control (C, D) groups (average ± SD). RMS data were reported as a percentage of the maximum voluntary concentric contraction at angular velocity of 60°/s. ∗$P < 0.05$ compared to pre-exercise (Pre) value.

Fig. 4. Peak torque of knee extension (A, C) and flexion (B, D) and 30-m running (E, F) performance changes in elastic band training (EBT) and control (CON) groups (average ± SD). ∗$P < 0.05$ compared to pre-exercise (Pre) value.