

Effect of post activation potentiation induced by elastic resistance on kinematics and performance in a roundhouse kick of trained martial arts practitioners.

Running head: PAP and performance of roundhouse kick

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ABSTRACT

The aim of this study was to examine if kicking with elastic resistance during warm-up could initiate Post-Activation Potentiation (PAP), and thereby positively influence kinematics and performance on subsequent explosive roundhouse kicking. Five women and eleven men (n=16) with a background in kickboxing (n=10) and/or TaeKwonDo (n=6) performed two warm-up strategies with three subsequent test-kicks 5-8 minutes after a PAP inducing exercise. Kicking performance, defined as roundhouse kicking velocity with the foot, was measured using 3D motion capture (500 Hz) with a 15 marker lower body 3D model. In addition, electromyography of the prime movers; vastus lateralis, vastus medialis and rectus femoris muscles, was measured to confirm the presence of PAP. Kicking velocity of the foot increased by 3.3% after performing a warming-up strategy including kicking with elastic resistance ($p=0.009$, $\eta^2 = 0.32$). Increases were also recorded in muscle activity in vastus medialis (35.2%, $p=0.05$, $\eta^2 = 0.18$) and rectus femoris (43.9%, $p=0.04$, $\eta^2 = 0.20$). These findings indicate that performing a warm-up strategy including kicking with elastic resistance can have a positive effect on kicking performance in a roundhouse kick.

KEY WORDS: Warm-up, explosive, PAP, resistance, combat sports.

INTRODUCTION

Warming up before a performance has been used to prepare and enhance the upcoming performance in combat sports. A mechanism that is associated with warming up, known to positively influence performance in explosive movements, is Post-Activation Potentiation (PAP) (6, 16, 17). Improvements in performance that follow after a submaximal or a maximal contraction has been referred to as PAP (4). One theory explaining PAP deals with physiological improvements such as phosphorylation of regulatory light chains (RLC) (24), increasing calcium (Ca^{2+}) sensitivity of the actin-myosin complex, increased enzyme activity (22) and increased rates of actin-myosin cross-bridging (12). These enhancements could increase the muscle's power output due to an increase in contraction velocity. Another theory regarding PAP deals with neurological enhancements. This theory involves an increased recruitment of higher order motor-units (7, 9), better synchronization of the motor units and reduced pre-synaptic inhibition (1, 2). With such enhancements, electromyography could indicate the presence of PAP during testing.

Previous studies presented inconsistent findings of PAP and improvements in performance. Some studies have shown improvements in performance (3, 7, 17, 19), while other studies have not been able to measure an effect of PAP (5). Some studies have used maximal voluntary contractions (MVC) (3, 5), while other studies have used heavy resistance weightlifting exercises (7, 14, 17, 19) with the intention to initiate PAP. Even so, for many sports there is a lack of specificity in using such exercises to initiate a short-term positive effect on performance.

Smith et al. (21) applied sprinting with resistance in the form of a sledge with the intention of initiating PAP, which was more biomechanically similar and specific to the following sprinting exercise. Training using dynamic roundhouse kicking with additional elastic resistance has previously shown to chronically increase kicking performance in terms of velocity (13). However, using elastic resistance as an exercise to initiate a short-term positive effect (PAP) on performance has not yet been studied. Furthermore, most of the previous studies have only measured performance changes, not kinematic and muscular alterations following PAP induction (3, 7, 16, 17, 19). These eventual kinematic and/or muscular changes could give more information about what actually causes changes in performance.

Therefore, the purpose of this study was to examine if kicking with elastic resistance could initiate PAP, positively influence kinematics and thereby performance on subsequent explosive roundhouse kicking. It was hypothesized that kicking with elastic resistance at the end of a warm-up protocol would improve short-term kicking kinematics and performance of the trained martial arts practitioners. Furthermore, that this effect was caused by the increase in muscle activity in the kicking legs' knee extensors due to PAP.

METHODS

Experimental approach to the problem

To investigate if roundhouse kicking with elastic resistance in the warming up caused a PAP effect on subsequent kicking performance a randomised crossover study was conducted with two warm-up protocols: one protocol with kicking with elastic resistance and the other without. The dependent variables were maximal velocity of the distal endpoints of foot, knee

and hip, angular velocities of different joint movements and muscle activity of the prime movers of the knee extension.

Subjects

Five female and eleven male martial arts competitive athletes (age 20.6 ± 5.5 years, height 175.6 ± 8.9 cm, weight 75.5 ± 13.5 kg, BMI 24.5 ± 4.1 kg/m², 3.8 ± 2.5 years of experience practicing taekwondo and/or kickboxing) participated in the study. The subjects were informed of the benefits and risks of the investigation and a written informed consent was obtained prior to all testing from all participants and their parents (if they were younger than 18 years). The study was complied with the regional committee for medical research ethics and the current ethical standards in sports and exercise research.

Procedures

On each occasion, the participants performed one of the two warm-up protocols followed by the roundhouse kick. The warm-up protocol (control) started with five minutes of light jogging before performing one minute repeated ballistic hip movements per exercise at low to moderate intensities (outwards and inwards rotation, high knees, and heel flicks). Next in the warm-up protocol were low-intensity scissor kicks performed continuously for two minutes. After this, a front step technique resembling a single high knee with a forward leap was performed continuously for two minutes. The last part of the warm-up protocol included two sets of 10 roundhouse kicks on each foot on a kicking shield. The roundhouse kick is used since it is one of the most commonly utilized kicks of the martial arts practitioners' repertoire (15, 23). There are many variations of the roundhouse kick, but general execution of the kick is described as follows. From a fighting stance the martial arts practitioner applies force to the

ground with the kicking leg and perform a forward thrust with his hip. The kicking leg moves close to the standing leg forwards and upwards until the thigh is just about level with the ground. Until this point, the calf and foot will be hanging down towards the ground from the knee. The lower leg would now be pronated until the calf is at a 45-90° attack angle towards the target whilst extending the knee activating the prime movers and hitting the target. The individual practitioner would adopt the technique and perform the kicks in their way to account for their anthropometry. For a more detailed description of the roundhouse kick used in this study see <http://taekwondobiomechanics.blogspot.co.nz/>. The second warm-up protocol included the same standardized pre-competition warm-up routine with an additional 10 kicks with an elastic resistance tube (X-ERFIT FITNESS TUBE, Mjøndalen, Norway) fastened around the ankle joint in three sets with 90 seconds pause, which was sufficient for maintaining maximal performance and complies with the theory of recovery of power (18). The elastic tube was anchored to a heavy stationary object before kicking. The subjects started on a position in which the tube was under tension (30 N) as measured with a load cell. Then ten proper kicks with the elastic tube around the ankle were performed in which the elastic tube was stretched with a resistance of around 60 N. If the subjects were not able to perform proper technique whilst kicking they were asked to decrease tension on the elastic tube (move away or closer to anchor point) until they managed to maintain proper technique.

To measure muscle activity electromyography (EMG) was measured. After performing one of the warm-up protocols the test subjects had a 5-8 minutes rest before kicking performance was tested, since Wilson et al. (26) found that the largest PAP effect in trained athletes was around this time. In this time markers, surface EMG sensors and electrodes were fastened (Dri-Stick Silver Circular sEMG Electrodes AE-131, NeuroDyne Medical, USA). The skin

on which the electrodes were fastened had been shaved and washed with alcohol before fastening the electrodes. The electrodes (11 mm contact diameter and 2 cm centre-to-centre distance) were placed along the presumed direction of the underlying muscle fibre on the vastus lateralis, vastus medialis and rectus femoris muscles according to the recommendations of SENIAM (11). The EMG raw signal was amplified and filtered using a preamplifier located as close as possible to the pickup point with the intention of minimizing the noise induced from external sources through the signal cables. The preamplifier had a common mode rejection ratio of 100 dB. The EMG raw signal was then bandpass filtered (fourth-order Butterworth filter) with cut-off frequencies of 8 Hz and 600 Hz. The resulting EMG signals were converted to Root Mean Square (RMS) signals using a hardware circuit network (frequency response = 0–600 kHz, averaging constant = 100 ms, total error = \pm 0.5%). During the kick, the average EMG activity of the vastus lateralis, vastus medialis and rectus femoris muscles, from toe-off to contact with the bag, was used for further analysis. Since a subject design was used with tests on the same day, without removing the EMG equipment from the subjects between the two protocols, it was not necessary to normalize EMG data. Thereby, an eventual PAP effect caused by including maximal isometric contractions of the involved muscles to normalize the EMG data, was avoided.

The roundhouse kicks were performed with maximal effort on a hanging heavy-bag after the markers, EMG sensors and electrodes had been fastened. The three test kicks were measured using a three-dimensional (3D) motion capture system (Qualysis, Gothenburg, Sweden) with six cameras operating at a frequency of 500 Hz to track reflective markers, creating a 3D positional measurement. Fifteen markers were fastened on each side of the body on the iliac crest and greater trochanter, on the lateral and medial epicondyle of the femur, on the lateral and medial malleolus and on the distal ends of the metatarsal I and V. The 3D motion capture

system was synchronised with wireless EMG recordings using a Muscledlab 6000 system and analysed by Muscledlab10.73 software (Ergotest Technology AS, Langesund, Norway). Computation was conducted on maximal linear velocity of the kicking foot's lateral markers (distal foot, ankle, knee and hip) together with the maximal angular velocity of joint movements (knee-, hip- extension and hip rotation) and their timing. All calculations were performed in Matlab 6.1 (The Mathworks Inc., MA, USA). The time of impact of the foot on the heavy bag was set to zero and timing of the maximal velocity of the linear endpoint of the different body segments and joint movement was presented as the time before impact. Only data from the best kick (highest linear foot velocity measured) was used for further analysis.

Between the two protocols participants had a minimum 30-minutes break before starting the next warm-up protocol to ensure that any effects of PAP had diminished before starting the next warm-up protocol (24).

Statistical analyses

To compare the effect of warm-up with and without elastic resistance a one-tailed paired T-Test was used on the dependent variables. The level of significance was accepted at $P < 0.05$ and all data are expressed as mean \pm SD. Effect size was evaluated with η^2 (ETA partial squared), where $0.01 < \eta^2 < 0.06$ constitutes a small effect, $0.06 < \eta^2 < 0.14$ constitutes a medium effect, and $\eta^2 > 0.14$ constitutes a large effect (8).

Reliability of the kicking kinematics and EMG was based upon the three kicks and was tested by Intraclass Correlation Coefficient (ICC) based upon the using Cronbach's alpha. The ICC of the kicking kinematics and EMG responses were all > 0.97 . Statistical analysis was performed using SPSS 21.0 for Windows (SPSS, Inc., Chicago, IL).

RESULTS

For the kicking foot's toe, linear velocity was 3.3% higher ($p = 0.009$, $\eta^2 = 0.32$) after conducting the warm-up with elastic resistance (17.93 ± 2.26) compared to the one without (17.35 ± 1.97 m/s; Fig. 1). In addition, the kicking foot's knee attained a 2.5% higher linear velocity (without ER: 7.16 ± 0.96 m/s, with ER 7.34 ± 1.07 , $p = 0.028$, $\eta^2 = 0.22$), while the hip and ankle had no significant change in linear velocity ($p = 0.059$, $p = 0.092$ respectively, $\eta^2 \geq 0.11$). No significant differences in timing of maximal velocity of the different endpoints between the two conditions were found ($p \geq 0.13$; Fig. 2). In addition, no significant differences for the maximal angular velocity of the joint movements (hip rotation and extension and knee extension) were found ($p \geq 0.13$).

FIGURE 1 and 2 NEAR HERE

However, significant difference in time of occurrence of maximal angular velocity of the knee extension ($p = 0.019$, $\eta^2 = 0.29$) and hip rotation ($p = 0.021$, $\eta^2 = 0.30$) were found (Fig. 3). An earlier occurrence of hip rotation was found when kicking after warming up with elastic resistance compared with the warming up without elastic resistance, while the opposite was found for the maximal knee extension velocity (Fig. 3).

FIGURE 3 NEAR HERE

Significantly higher EMG activity was observed only in the rectus femoris (without ER: 104.96 ± 80.13 μ V, with ER: 151.11 ± 131.26 μ V, $p = 0.04$, $\eta^2 = 0.20$) although it also trended higher in the vastus medialis (without ER: 157.23 ± 66.76 μ V, with ER: 212.64 ± 151.59 μ V, $p = 0.06$, $\eta^2 = 0.18$). EMG activity was unchanged in the vastus lateralis ($p = 0.36$).

FIGURE 4 NEAR HERE

DISCUSSION

The aim of this study was to examine if kicking with elastic resistance could initiate PAP, positively influence kinematics and thereby performance during subsequent explosive roundhouse kicking. The major findings, as hypothesized, include a positive effect on roundhouse kicking performance following a warm-up routine including roundhouse kicking with elastic resistance. Furthermore, a higher recorded EMG activity of the rectus femoris after the elastic resistance warming up which confirmed the presence of PAP.

A performance improvement of 3.3 % after including elastic resistance in the warm-up protocol in the present study is comparable with the 2.9% increase in counter-movement jump height (17) and 1-2% sprint performance increase subsequent to a PAP warm-up protocol (21). Mitchell & Sale (17) conducted 5-RM squats to induced PAP for CMJ performance, while Smith et al. (21) used sledge runs with 0, 10, 20 and 30% of the athletes' body weight to investigate its PAP effect upon sprint performance. Both studies argue that a PAP-effect potentially contributed to the increased performances. However, Mitchell & Sale (17) did not report any recording of EMG or kinematic data during the CMJ testing. Hence, possible differences in kinematics, timing or changes in the proximal distal sequential chain were not analysed that can explain an eventual PAP effect. Smith et al. (21) reported significant differences in kinematics when between 0%, 10%, and 20%, 30% loads, which could resemble the differences found in kinematic timing in the present study and a PAP effect. However, between the different loads no significant differences in sprint performances were found. Therefore, despite the performance increase, this study fails to report any

findings or use of instrumentation with the intention of investigating the presence of PAP. Consequently an uncertainty of the presence and contribution of the PAP-effect on the performance increase remains.

In the present study, elastic tubing were used as resistance with the intention of inducing PAP. The principle of using elastic tubing as resistance is that the tubes can increase force production during the whole range of motion (20). Such a resistance profile could potentially better stimulate the entirety of the muscle, rather than the biomechanically heavier start and gradual ease of using weighted equipment at lower loads. Additionally, the elastic tubing are thought to add resistance to complex multidimensional techniques without influencing the technique with too much bias. However, the influence elastic tubing could have on technique would be depending on the users' familiarity with the use of elastic tubing.

To our best knowledge only Wyland, Van Dorin and Reyes (27) have conducted a study that combined the use of heavy resistance, with and without resistance bands, to initiate PAP with an additional control condition observing their effects on subsequent sprinting performance. In their study Wyland, Van Dorin and Reyes (27) did not find any significant changes in sprint time across post-testing times during the control and the 'standard' heavy resistance squats (5 sets of 3 reps at 85% of 1-repetition maximum) condition. They did, however, find a significant decrease between the post-immediate and post-4min sprint time after performing the heavy resistance squats with additional elastic resistance. Even though the present study did not conduct a test immediately after warm-up, the similarities between the studies regarding performance increases remain. Previously, it was discussed how the specificity of squatting exercises are not biomechanically similar to sprinting. However, it is quite

interesting that Wyland, Van Dorin & Reyes (27) included resistance bands in their study and thereby contributed to further investigation the effects of gradually increasing resistance due to the elasticity of the bands. It was also quite interesting to see that they found an increase in performance using elastic bands, but no differences after 'standard' heavy resistance squats (5 sets of 3 reps at 85% of 1-repetition maximum). The resistance-profile of elastic sports-equipment is different from a relatively constant resistance given by heavy resistance exercises and lighter resistance exercises. These differences, and their impact on the PAP effect should be investigated further.

The improvement in kicking performance was compliant with the theory of neural enhancements. Increased recruitment of higher order motor units (7, 9), a better synchronisation of the involved motor units and a reduced pre-synaptic inhibition (1, 2) could all contribute to a faster kick. The results presented in this study included a significant increase in maximal muscle activity of the rectus femoris. As a prime mover of the knee extension, this increase could have caused a higher knee extension, however, a higher knee extension was not found in the present study. Even though no significant changes in terms of maximal angular velocity of knee and hip extension and hip rotation were found, differences in timing of maximal angular velocity of the hip rotation (earlier) and knee extension (later) when kicking after the elastic resistance warm-up were found. These timing differences found in the maximal knee extension velocity could perhaps explain the performance differences of the two warm-up protocols due to a longer acceleration time giving a later maximal velocity. This indicates a change in the proximal distal sequential chain from kicking without elastic resistance to kicking with elastic resistance. The time between the two maximal joint movement velocities (hip rotation and knee extension) increases after

performing a warm-up including elastic resistance, which could create more tension to the distal movements of the kick. Thereby, the timing of this whip-like movement (25) could be responsible for the change in kicking velocity.

The increased kicking velocity could come from physiological enhancements involving a shorter path for myosin heads (24)⁵, increased supply of ATP (12) and heightened sensitivity for Ca²⁺ (22). Thus, increasing the rate of cross-bridging and a greater muscular contraction velocity could explain the increased kicking velocity. In addition, changes in pennation angle are thought to provide a greater transmission of power from the muscle to the moving structure (24). The increased kicking velocity recorded in this study could have benefitted from a greater transmission of power from the muscle to the moving structure. However, the physiological changes that are proposed to occur as a result of PAP were not possible to measure. Only eventual pennation angle changes are possible to measure in the current set up by using ultrasound measurements (10). Therefore, future studies should include ultrasound measurements to investigate if these changes in kicking performance is attributed by changes in pennation angles.

PRACTICAL APPLICATIONS

The present study shows that a warm-up strategy that includes kicking with elastic resistance caused a positive effect in the kicking performance for trained martial arts practitioners. The forethought effects of PAP could have caused the 3.3% increase in the kicking-foot's distal velocity. The increased muscle activity indicates that the PAP effect could have been present after kicking with elastic resistance. Such effects could deem it beneficial to include kicking with elastic resistance as part of a pre-competition warm-up protocol. These results could

have important implications for athletes, coaches and physical-training staff to help them increase short-term performance. Furthermore, elastic tubes are very portable and including them as part of a warm-up routine is very feasible. However, more research regarding the effects of PAP on performance in during competition, under continuous strain and fatigue, should be conducted before using this method of enhancing performance in a competition.

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Figure legend

Figure 1:

Change of kicking velocity with elastic resistance on kicking performance measured at the distal end point of foot in roundhouse kicks by each participant compared with maximal kicking velocity after warming up without elastic resistance.

Figure 2:

Maximal linear velocity of the distal endpoint of the hip, knee ankle and foot after warm-up with (○) and without (▲) elastic resistance and their timing relative to impact.

*Significant difference in maximal velocity between the two conditions ($p < 0.05$).

Figure 3:

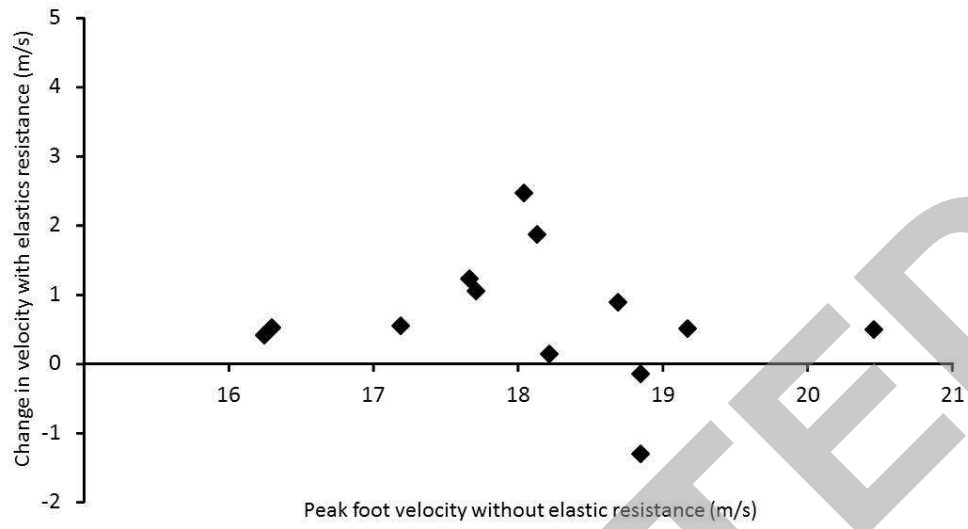
Maximal angular velocity of hip extension, hip rotation and knee extension after warm-up with (○) and without (▲) elastic resistance and their timing relative to impact.

*Significant difference in timing between the two conditions ($p < 0.05$).

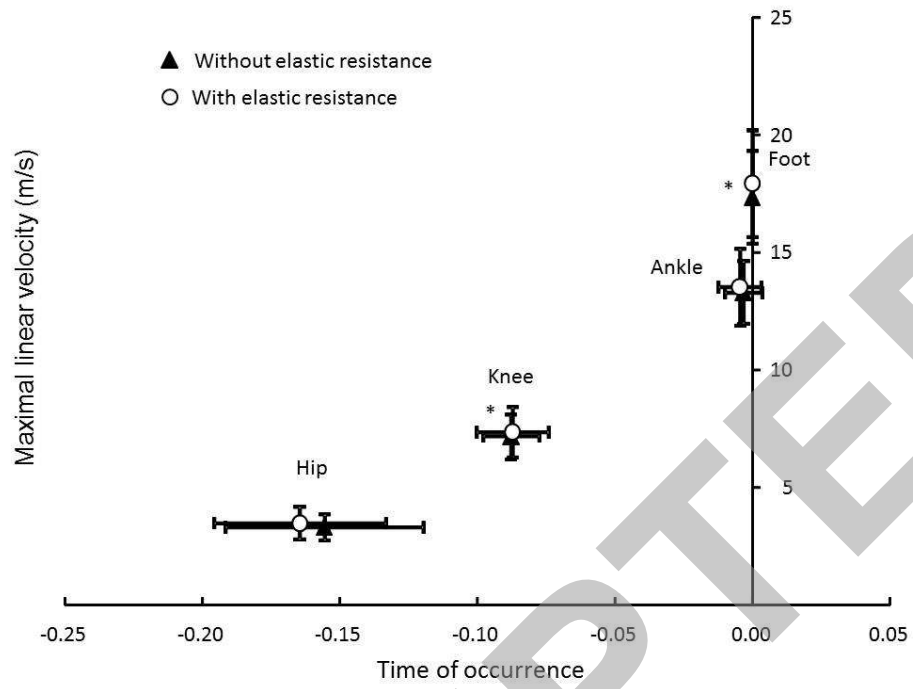
Figure 4:

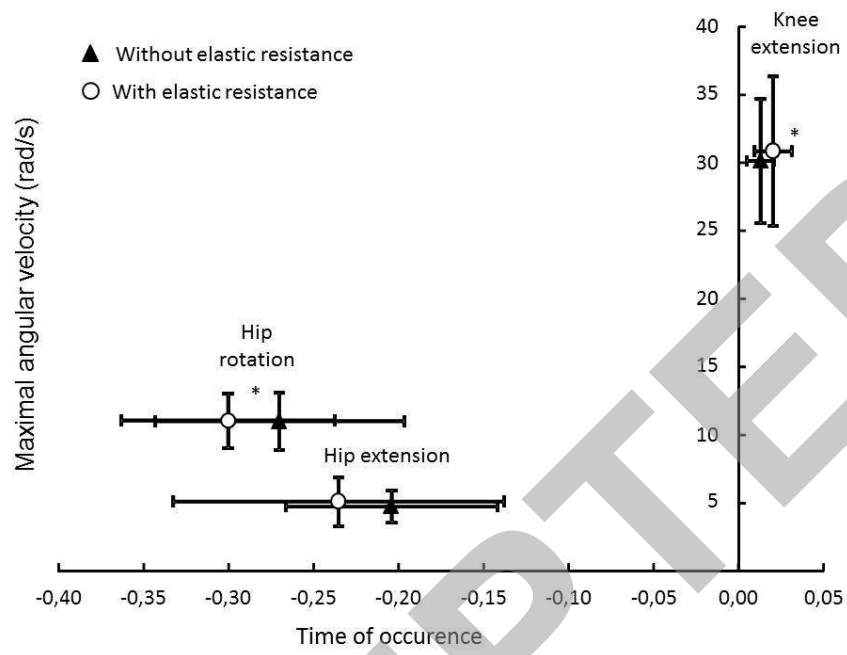
Mean RMS measured during kicking of the vastus medialis and vastus lateralis and rectus femoris

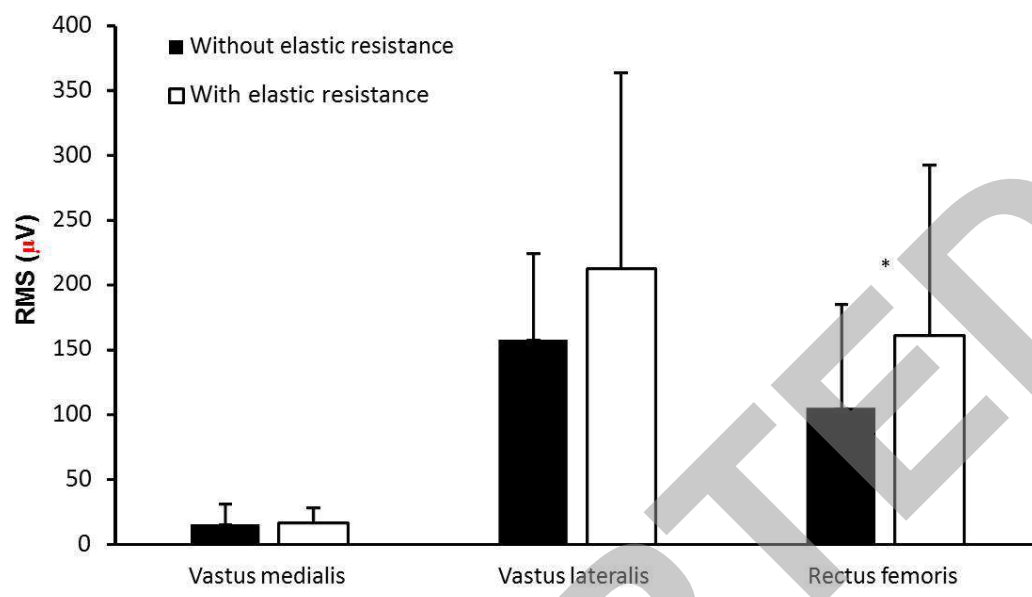
*Significant difference between the two conditions ($p < 0.05$).



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