Nedim Čović[1]

DOES BACK SQUAT ALTERNATE VELOCITY DIFFERENTLY EFFECTS KNEE MUSCLES PEAK POWER AND HAMSTRING TO QUADRICEPS RATIO IN SEMI-ACTIVE ADULTS – RANDOMIZED CONTROL TRIAL

[1] *Faculty of Sports and Physical Education, University of Sarajevo, Bosnia and Herzegovina*

Original scientific paper
UDC: 796.012.424

Abstract
Aim of the study was to compare the effects of the low intensity back squat performed at alternate velocities on power, strength and H/Q ratio. The study was conducted on male students population (n=33) randomized in slow speed group (STG), fast speed group (CSTG) and controls (CG). Main study outcome was significant improvement in squat 1RM with 22.8% and 25% for the STG ($p<0.001$) and CSTG ($p<0.001$), 6.3% quadriceps peak torque of the lessdominant (PTQ l, $p<0.001$) for the STG, and 3.4% dominant limb peak torque (PTQ d, $p=0.045$) in CSTG. STG increased their both leg average thigh circumference (CT) by the 6.7% ($p<0.001$). Both STG and CSTG had no significant changes in hamstring peak power and hamstring to quadriceps ratio (H/Q ratio). Results are suggesting that speed of the back squat performed does not differently affect power and strength and that variability of the intensity is most important for the power increase. Squat 1RM improvement was probably caused by the technique adaptation and CT increase in STG. CSTG improved their 1RM due to technique efficiency improvement. Further researching should be conducted in terms for marking the body adaptation mechanisms to alternate squat speed at same intensity.

Key words: **strength, speed, power, stretch-shortening cycle, technique, thigh circumference**

Introduction

Speed, power and strength are the most common terms used by the coaches when talking about sport fitness performance. It is unusual to have an athlete that possesses great strength, and the ability to generate it rapidly (Newton & Kraemer, 1994). Several authors confirmed correlation between speed and power (Nykytenko et al., 2013; Zatsiorsky, 2008), strength and power (Zatsiorsky, 2008) and squat, strength and power (Rhea, Alvar, Burkett, & Ball, 2003; Rhea, Kenn, & Dermody, 2009; Zatsiorsky, 2008). A well known fact is that high level and elite athletes perform squat to optimize and maximize lower body strength and power. Also, it is the most common exercise of choice for the legs muscle hypertrophy among semi active recreational population.

Injuries among this population are not that common due duration of activity, intensity and longer rest to training ratio. Hamstring strain, ankle sprain and twists, tendinitis, mechanical caused lesions and ALC ruptures are the most common injuries in semi-active population (Pope, 2000). However, serious knee injury factors are imbalances between quadriceps and hamstring muscles and bilateral strength asymmetries. According to Youdas (2007) males can dominantly, by 3.5 times more, activate hamstrings in contrast to female while performing one leg squat. Fact that squat affects hamstrings and quadriceps strength can be used as reasonable explanation for the possible H/Q strength ratio changes. In kinetic chain of lifting extensors are in concentric mode while flexors do eccentric movement. Since the total force is greater when eccentric movement is performed there is a possibility that knee flexors might have greater stimuli and increase H/Q ratio.

A squat lifting pace or velocity of the movement can be considerate as integral part of back squat lifting technique (Van Dieen, Creemers, Draisma, Toussaint, & Kingma, 1994). Technique can have opposite effect on speed mainly depending on freely chosen lifting technique (Bush-Joseph, Schipplein, Andersson, & Andriacchi, 1988). The velocity of lifting can impair lower back pain, spine compression and back load (van Dieën, Hoozemans, & Toussaint, 1999). However, a little was known about the interaction of lifting velocity and how it actually effects strength and power output. Several studies (Newton &

Kraemer, 1994; Rhea et al., 2009; Wallace, Winchester, & McGuigan, 2006) investigated different variations of squat speed and intensity and its transfer on power, strength and speed output. Mainly, authors suggested greatest effect in power increase when variable resistance (RFD) was used, especially in early stages of the lift.

Reasonable and rationale question is does different squat speed with same intensity plays significant role in strength and power training. Speed alternations are related to weight lifted and depends upon motor control ability, biomechanical advantages, muscle type tissue and nervous system (Rhea et al., 2003). Probably the easiest way to control speed variable is by restricting the total time for the each lift. It is fairly reasonable to research presented facts since alternative speed of the squat same weight resistance can differently affect power and strength of the lower extremities. Other study aim is to establish evidence and relation of squat exercise and the injury risk factors. From the previously stated emanates main aim of the study, does alternations in squat movement speed produces different effects. Adaptation for the stimulus shall be evaluated true literature search with possible theoretical explanations. It is hypostasized that squat speed plays important variable for maximizing the squats exercise potential.

Methods

Study design and participants

Study was designed as randomized control trial (RCT). In brief, participants were students of the Faculty of Sport and Physical Education in Sarajevo. Eligibility of subjects was set by inclusion criteria: Semi active adults (over 18 years of age), without any neuromuscular diseases and knee, ankle and hip injuries in last 24 months and H/Q ratio lower than 70% (>0.70) (Draganidis et al., 2015). The main criteria for exclusion preliminary were level of physical activity (more than 4 sessions missed true training intervention), pain and lower back injuries. All the subjects had to perform proper deep squat movement without assistance true full range of motion. Squat efficiency were evaluated by functional movement marks (FMS) (Cook, Burton, & Hoogenboom, 2006). For the candidates that scored marks lower than two (<2) were considered ineligible for the study and exclusion had to be made.

Regarding the study design, first (STG) and second (CSTG) intervention group performed squat training at different squat velocities two to three times per week in 12 week training period while third (CG) group maintained their lifestyle. In overall 33 male participants (mean ± SD: age: 19.7±0.68 years; height: 184±7.4 cm; weight: 77±7.8 kg; BMI: 22.5±1.7 kg/m^2) were randomly allocated in ratio 1:1:1. No significant differences were observed for age, height, weight and BMI values at the base line. Testing procedures included isokinetic concentric quadriceps and hamstring muscle force output and back squat one repetition maximum (1RM) Study has been previously approved by the Faculty of Sport in Sarajevo. Subjects were fully verbally informed about the testing and training procedure.

Table 1. Subjects characteristics

	STG *(n=11)*	CSTG *(n=11)*	CG *(n=11)*
Height (cm)	187.2±7.6	182.6±6.6	182.2±7.4
Mass (kg)	81.3±7.7	77.4±5.5	72.4±7.9
Age (years)	20±0.63	19.4±0.5	19.7±0.8
BMI (kg/m2)	22.7±1.5	23.2±1.5	21.7±1.9

Data are expressed as mean±SD
STG – low squat velocity
CSTG – high sqaut velocity
CG – control group

Training intervention

For experimental groups training intervention featured performing back squat at 70% of one maximal successful effort. STG subjects were asked to do each lift (eccentric + concentric) for at least 4 seconds time period, and were verbally guided on the squatting speed adjustments during execution as well as for technique. On the other hand CSTG participant's task was to try to finish each lift for the shortest time possible. For the safety reasons two assistants from each side of squat rack were allowed. Training treatment lasted 12 weeks on average 2-3 times per week. Training intensity and overall load did not increase nor decrease during this period. Each participant was subjected to identical warm up protocol starting with 10 minutes of ridding bicycle ergometer at 75 W followed by set of 7 dynamic stretching exercises repeated in 2 sets by 10 repetitions for each limb. In brief, warm up lasted on average (mean±SD) 17±1.3 min. Total number of training sessions for the STG and CSTG were 28.6 (2.4 per week) and 29.9 (2.51 per week) for each individual. Darthfish software (Fribourg, Switzerland) for video analysis has been used to determine average velocity and duration of each repetition as well as KF and KE phase time measurement and foot angle. In order to achieve optimal squat dept and angle of 90˚ between lower leg and thighs, protractor and height variable bench were used and adjusted for each participant respectively.

Testing and measuring procedures

All the participants were familiarized with testing procedures on both testing accessions (T1 and T2). Ninety degrees squat (Straker, 2002) without variations has been applied as representative measurement tool. A standard Olympic weightlifting set (Eleiko weight set) was used. Procedure of 1RM testing had standardized protocol starting with squatting with barbell only (20 kg) for 10 times. Testing for all the subjects started from 50 kg with 5 kg increase. Result that count was last successful lift with right angle and depth. No assistance was allowed.

Table 2. Main features of the 12 weeks squat training intervention for the STG and CSTG

	STG *(n=11)*	CSTG *(n=11)*		STG *(n=11)*	CSTG *(n=11)*
Intensity (70% of 1RM)	49.63±15.6	43.89±8.9	KE phase (s)	2.2±0.2**	0.8±0.3
Volume (No of sets / No of repetitions)	3/10	3/10	KF phase (s)	2±0.1**	1.1±0.2
Volume (kg per week)	3.571	3.305	Stance range (cm)	35-49	38-51
Time of each repetition (s)	4.2±0.3**	2.9±0.6	Foot angle° (deg)	5-10	5-10

Data are expressed as mean±SD
*** - p<0.01 compare to CSTG*
** - p<0.05 compare to CSTG*

Isokinetic concentric knee muscles contractions expressed as peak torque (PT) in Newton meters (Nm) were measured at angular velocity of 60°/sec. Isokinetic dynamometer (Biodex Medical Systems, Shirley, New York) was used in order to determine parametrical hamstring and quadriceps (KE and KF) peak power (dominant and less dominant extension and flexion peak torque) and power ratio in both limbs. After completing warm up and functional movement screening, and measuring both legs average thigh circumference (CT) without skinfold thickness correction (Martin, Spenst, Drinkwater, & Clarys, 1990) standardized protocol of 5 maximal voluntary contractions with 80° range of motion was conducted (starting point at knee flexion of 90°). Dynamometer pole axis was lined up with knee rotational axis and the static correction of gravity was measured at 30° prior to beginning of the test (Parsons & Porter, 2015). Chair sitting positing was set at 85°. Monitored isokinetic power variables in study were: quadriceps peak torque (PTQ d and PTQ l), hamstring peak torque (PTH d and PTH l) and hamstring to quadriceps ratio (H/Q d and H/Q l) for dominant and less dominant limbs.

Statistical analysis

Normality of data distribution was determined using Shapiro-Willk's test and Q-Q plots. Between groups differences and training intervention effects were evaluated using factorial two-way repeated measures analysis of variance (ANOVA, group x time). When significant difference was revealed a Bonferroni post hoc test was used. Pre-post intervention and baseline differences were assessed using simple ANOVA with Bonferroni post-hoc test. All the data analysis has been done using software package for statistical analysis (SPSS 23.0, IBM Corp.). Data are expressed as mean values and standard deviations if otherwise not stated. Relative training effects and changes in results are presented as percentages. Statistical significance was set at $p<0.05$.

Results

Training intervention

No significant differences for the pre testing results in training intensity, volume and squat were observed between groups. The total time of squat execution was lower for the CSTG compare to the STG ($p<0.001$). For the STG concentric squat phase lasted markedly longer then in CSTG ($p<0.001$) as well as for the eccentric phase ($p=0.034$). In comparisons of the foot stance range and foot angle during the 12 weeks training period no differences were highlighted.

Table 3. Hamstring to quadriceps torque ratio of dominant (H/Q d) and less dominant (H/Q l) limb, Peak torque of dominant (PTQ d) and less dominant (PTQ l) limb quadriceps and hamstrings (PTH d and PTH l) and squat and thigh circumference for low speed squat (STG), high speed squat (CSTG) and control (CG) group before (T1) and after 12 weeks (T2) of intervention

	STG *(n=11)* Mean ± SD			CSTG *(n=11)* Mean ± SD			CG *(n=11)* Mean ± SD		
	0 Weeks (T1)	12 Weeks (T2)	Δ%	0 Weeks (T1)	12 Weeks (T2)	Δ%	0 Weeks (T1)	12 Weeks (T2)	Δ%
Squat 90° *(kg)*	70.9 ± 12.2	91.8 ± 11.7**§	22.8	62.7 ± 12.7	83.6 ± 12.86**‖	25	60.9 ± 15.7	64.5 ± 16.3	5.6
H/Q d *(%)*	51.5 ± 8.4	52.6 ± 4.1	2.1	56.9 ± 7.8	56.6 ± 7.8	-0.6	53.7 ± 5.8	55.5 ± 7.6	3.2
H/Q l *(%)*	53.6 ± 6.3	50.4 ± 6.1¶	- 6	49.9 ± 5.9	53.1 ± 7.9	6.1	51.2 ± 4.7	52.3 ± 7.5	2.2
PTQ d *(Nm)*	238.9 ± 14.9†	248.9 ± 18.5§¥	4.1	217.3 ± 17.2	224.9 ± 21.4*	3.4	210 ± 15.8	215.9 ± 20.6	2.8
PTQ l *(Nm)*	223.3 ± 19.1	238.3 ± 20.2¥**	6.3	217.9 ± 26	219.7 ± 28.1	0.9	210.1 ± 21.9	208.5 ± 19.6	-0.8
PTH d *(Nm)*	122.6 ± 18.2	127.4 ± 16.6	3.8	124.1 ± 21.9	127.1 ± 21.5	2.4	113.8 ± 18.6	119.2 ± 14.8	4.6
PTH l *(Nm)*	119.4 ± 14.7	122.7 ± 16.8‡	3.1	109.2 ± 21	116.4 ± 22	6.2	107.3 ± 14.9	108.5 ± 15.3	1.2
CT *(cm)*	53 ± 2.6	56.8 ± 2.3**¥	6.7	52.1 ± 3.1	53.2 ± 3.3	2.1	53.6 ± 2.1	53.4 ± 2	-0.4

** - T1 < T2; p < 0.05. ** - T1 < T2; p < 0.001. ¶ - T1 > T2; p < 0.05. † - T1 (STG > CG); p< 0.05. ‡ - T2 (STG > CG); p < 0.05. ¥ - T2 (STG > CG); p < 0.001. § - STG > CSTG p < 0.001. ‖ - T2 (CSTG > CG) p < 0.05.*

Squat and knee muscles peak torque and H/Q ratio

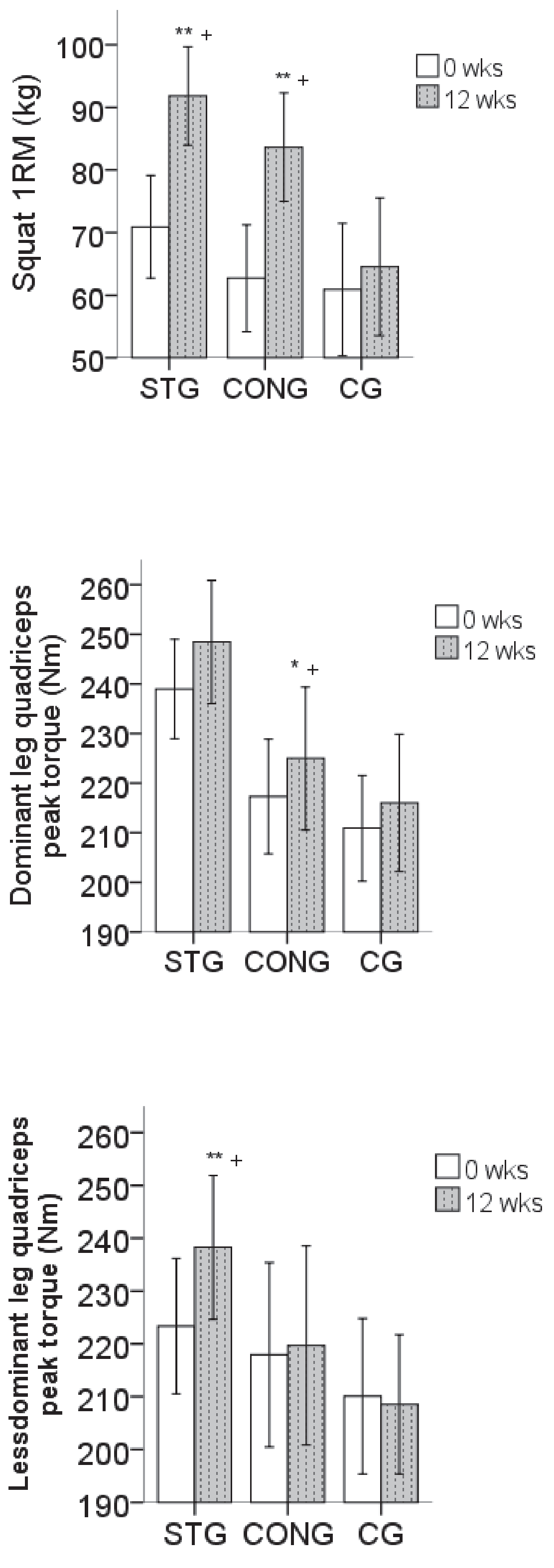

Figure 1. Back squat, peak torque of dominant and lessdominant leg before and after training intervention for STG (n=11), CSTG (n=11) and CG (n=11). Mean and CI 95% are presented. ** + improvement p<0.01. * + improvement p<0.05

Randomized groups did not differ at baseline, with exception of extension peak torque value of the dominant limb where STG had significantly higher result compared to CG (*p<0.001*) which maintained similar at the end of study. Training intervention for the experimental groups was clearly successful in terms of overall weight lifted in back squat. Both, STG and CSTG improved their squat performance in comparison with controls by ~16 % (*p<0.001; 95% CI 8.44-28.8*) and ~ 19 % (*p=0.042; 95% CI 0.27-20.6*). From baseline till study end STG improved squat result by 22.8% (*p<0.001; 95% CI 15.3-26.5*), CSTG even higher by 25% (*p<0.005;* 95% *CI 14.6 – 27.3*) while control group did not improve significantly. Extension peak power output of the dominant limb after 12 weeks in STG was raised insignificantly by 4.1%, while CSTG had 3.4% increase (*p=0.045; 95% CI 0.2-15.2*). At the end point when compared with controls and high speed group, STG achieved better results (*p<0.001; 95% CI 16.7 – 43.8 and p<0.001; 95% CI 9 – 36.1*). In less dominant side improvement was seen only for the STG subjects (*p=0.006; 95% CI 5.2 – 24.6*) which differ from the CG (*p=0.008; 95% CI 4.6 – 38.3*). Hamstrings peak power result of less dominant side after the treatment distinguished STG and CG significantly (*p=0.051; 95% CI 0.02 – 26.1*).
After 12 weeks of training H/Q ratio in STG decreased from 53.6% to 50.4% (*p=0.055; 95% CI 0.09 - 6.4*). For the subjects in STG thigh circumference significantly improved (*p<0.001*).

Discussion

The study examined effects of a 12 week strength training intervention with aim to determine wheatear there is a difference in changes of peak power performance and hamstring to quadriceps ratio in semi-active student population. The study compared influence of low intensity low speed repetition movement of back squat in contrast to low intensity high speed pattern movement. From baseline to study end point no drop outs were noted. By randomizing 33 subjects in three groups, results of strength parameters were measured on knees flexors and extensors using isokinetic dynamometer. Both types of training lead to significant improvement in weight of squat performance lifted (1RM) with some minor peak torque improvements and insignificant changes in hamstring to quadriceps ratio. In addition, only the STG group had significant improvement in the thigh circumference measure. For both, STG and CSTG no differences in training intensity and volume were present. Apparently, low intensity back squat performed at variable velocity does not provide adequate stimuli for physiological adaptations and power and strength performance increase according to the results presented.
Percentage improvement for both intervention groups was above 20% in weight increase for the back squat. With evidence of relatively poor peak power improvement in both limbs, previously stated fact is more likely due to body biomechanical and squat technique adapta-

tion (Kritz, Cronin, & Hume, 2009). A fact that subjects were relatively inexperienced in lifting technique supports mentioned fact, since there was space for improvement regarding the lifting efficiency and back posture (Anderson & Behm, 2005). Individual intensity used was 70% of initial squat performance and it is considered as small to moderate (Willardson & Burkett, 2008). By restricting most important strength improvement training variable (Rhea et al., 2003) the experiment was narrowed down to movement speed only. One study (Rhea et al., 2009) particularly researched back squat with various intensity and speeds (higher the speed lighter the resistance). Authors clearly stated that higher strength improvement happened in a group with lower speed with high intensity load. According to previous research by the same main author (Rhea et al., 2003) high intensity squat training impacts strength and power output by two mechanisms, muscle hypertrophy and neuromuscular adaptation (Baechle & Earle, 2008).

For the CSTG maintains unclear how did such marking strength improvement happened and beside technique efficiency adaptation, author suggests neuromuscular adaptation as well. The present study did not provide with adequate markers for muscle hypertrophy, with exception from tight muscles circumference. CT results suggested an overall muscle volume elevation for the STG only. Main cause of such result is due to work load over the time ratio. More controlled lifting caused stronger muscle contractions, which has been effective in hypertrophy increscent (Damas et al., 2015). Strength improvement in STG is mainly due to increase in muscles circumference and body to technique adaptation.

Although, leg lift was suggested true intervention time, power parameters did not improve linearly as squat result. As several researches suggested higher movement speed has an advantage in power increase over the other strength methods (Baechle & Earle, 2008; Newton & Kraemer, 1994; Rhea et al., 2009; Zatsiorsky, 2008). Furthermore, Rhea is suggesting that for maximizing power output crucial thing is resistance variability (RFD). Our study excluded all the variables, such as biomechanical lever advantages and RFD protocol (Edman, 2008) and by that it did not reach full potential for maximizing power performance. Stretch-shortening cycle (SSC) has specific energy transfer on which muscle tissue due to fast eccentric contraction stores elastic energy and during the concentric faze releases that energy, and that contributes in power improvement (Zatsiorsky, 2008). SSC occurs during the fast movements similar like in CSTG. Since no significant power improvement was found it is obvious that movement speed and lifting intensity could not gain effective SSC energy transfer. Similar but more significant improvements were found in STG and were caused probably due to strength improvement (Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004).

Hamstring to quadriceps ratio did not change significantly. Percentage change for dominant leg was around 3% and it was much smaller than the change for the lessdominant leg. Inconsistency of results can be seen by the decrease of H/Q ratio in STG. Several papers described and emphasized the importance of knee flexors to extensors strength ratio in terms of preventing hamstring and knee injury in recreationally active males (Hewett, Myer, & Zazulak, 2008). The 6% H/Q ratio increase for the lessdominant leg in CSTG is probably due to more intense eccentric movement then the one in STG.

Presented study did not give full explanation on the squat speed movement and its influence on power performance and H/Q ratio. Since the intensity of the training is much more important than the volume one can be said that 70% of 1RM squat was not superefficient for greater power improvement in semi active male population.

A 12 week of the same load intensity probably achieved muscle tissue adaptations initially in first 4 weeks but since no variability in weight was applied, further adaptation process could not maintain. Author personal opinion is that initial training benefits could not stay true additional 8 week period. Power outputs could be measured using force plate, or by the CMJ and drop CMJ which could potentially explained the effects of different squat speed in terms of performance enrichment.

In addition, for the further investigation of similar training and its effects could be determined using functional H/Q ratio and other power tests as well as the muscle biopsies and EMG. Body composition and legs muscle mass should be measured as well

Conclusion

Population that is fairly active in fitness, cross fit and recreational exercising programs usually performs low and moderate intensity back squat on regular basis. Depending of the technique level speed movement variability is used. By the results of the study it is obvious that there is neither significant difference nor valid evidence that semi active male population can benefit in H/Q ratio decrease or in power outputted performance. It can be stated that back squat improvement is mainly caused by the technique improvement.

References

Anderson, K., & Behm, D. G. (2005). Trunk muscle activity increases with unstable squat movements. *Canadian Journal of Applied Physiology, 30*(1), 33-45.

Baechle, T. R., & Earle, R. W. (2008). *Essentials of strength training and conditioning*: Human kinetics.

Bush-Joseph, C., Schipplein, O., Andersson, G., & Andriacchi, T. (1988). Influence of dynamic factors on the lumbar spine moment in lifting. *Ergonomics, 31*(2), 211-216.

Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: the use of fundamental movements as an assessment of function–part 1. *North American journal of sports physical therapy: NAJSPT, 1*(2), 62.

Damas, F., Phillips, S. M., Lixandrão, M. E., Vechin, F. C., Libardi, C. A., Roschel, H., Ugrinowitsch, C. (2015). An inability to distinguish edematous swelling from true hypertrophy still prevents a completely accurate interpretation of the time course of muscle hypertrophy. *European journal of applied physiology*.

Draganidis, D., Chatzinikolaou, A., Avloniti, A., Barbero-Álvarez, J. C., Mohr, M., Malliou, P., Margonis, K. (2015). Recovery Kinetics of Knee Flexor and Extensor Strength after a Football Match. *PloS one, 10*(6), e0128072.

Edman, K. P. (2008). Contractile performance of skeletal muscle fibres. *Strength and power in sport*, 114.

Hewett, T. E., Myer, G. D., & Zazulak, B. T. (2008). Hamstrings to quadriceps peak torque ratios diverge between sexes with increasing isokinetic angular velocity. *Journal of Science and Medicine in Sport, 11*(5), 452-459.

Kritz, M., Cronin, J., & Hume, P. (2009). The bodyweight squat: A movement screen for the squat pattern. *Strength & Conditioning Journal, 31*(1), 76-85.

Martin, A., Spenst, L., Drinkwater, D., & Clarys, J. (1990). Anthropometric estimation of muscle mass in men. *Medicine and Science in Sports and Exercise, 22*(5), 729-733.

Newton, R. U., & Kraemer, W. J. (1994). Developing Explosive Muscular Power: Implications for a Mixed Methods Training Strategy. *Strength & Conditioning Journal, 16*(5), 20-31.

Nykytenko, A., Nikitenko, S., Busol, V., Nykytenko, A., Velychkovych, M., & Martciv, V. (2013). Intercommunications of indexes of speed and power qualities of sportsmen single combat on the stage of the specialized base preparation. *Pedagogika, psihologia ta mediko-biologicni problemi fizicnogo vihovanna i sportu, 1*.

Parsons, J. L., & Porter, M. M. (2015). Reliability of Measuring Hip and Knee Power and Movement Velocity in Active Youth. *Pediatric Physical Therapy, 27*(1), 82-89.

Rhea, M. R., Alvar, B. A., Burkett, L. N., & Ball, S. D. (2003). A meta-analysis to determine the dose response for strength development. *Medicine and Science in Sports and Exercise, 35*(3), 456-464.

Rhea, M. R., Kenn, J. G., & Dermody, B. M. (2009). Alterations in speed of squat movement and the use of accommodated resistance among college athletes training for power. *The Journal of Strength & Conditioning Research, 23*(9), 2645-2650.

Straker, L. M. (2002). A review of research on techniques for lifting low-lying objects: 2. Evidence for a correct technique. *Work (Reading, Mass.), 20*(2), 83-96.

Van Dieën, J. H., Hoozemans, M. J., & Toussaint, H. M. (1999). Stoop or squat: a review of biomechanical studies on lifting technique. *Clinical Biomechanics, 14*(10), 685-696.

Van Dieen, J., Creemers, M., Draisma, I., Toussaint, H., & Kingma, I. (1994). Repetitive lifting and spinal shrinkage, effects of age and lifting technique. *Clinical Biomechanics, 9*(6), 367-374.

Wallace, B. J., Winchester, J. B., & McGuigan, M. R. (2006). Effects of elastic bands on force and power characteristics during the back squat exercise. *The Journal of Strength & Conditioning Research, 20*(2), 268-272.

Willardson, J. M., & Burkett, L. N. (2008). The effect of different rest intervals between sets on volume components and strength gains. *Journal of Strength and Conditioning Research, 22*(1), 146-152.

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British journal of sports medicine, 38*(3), 285-288.

Zatsiorsky, V. M. (2008). Biomechanics of strength and strength training. *Strength and power in sport, 2*, 439-487.

Submitted: October 13, 2015
Accepted: December 21, 2015
Correspondence to:
Nedim Čović, MA.
Faculty of Sport and Physical Education University
of Sarajevo
Bosnia and Herzegovina
E-mail: nedo_sprint@msn.com