MAXIMAL STRENGTH TRAINING IMPROVES STRENGTH PERFORMANCE IN GRAPPLERS

MST in BJJ athletes

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ABSTRACT

The aim of this study was to assess the short-term effects of maximal strength training (MST) as an accessory to grappling training on strength performance in competitive Brazilian jiu-jitsu (BJJ) athletes. Fourteen male BJJ athletes underwent measurements of one-repetition maximum (1RM) in the squat and bench press, rate of force development (RFD) and peak force (PF) in the squat jump (SJ), countermovement jump (CMJ) height, and muscular endurance in pull-ups, sit-ups and push-ups. Following baseline measurements, subjects were randomly allocated to either an MST group or control group (CON). The MST intervention consisted of 4x4 repetitions at ≥ 85% of 1RM in the squat and bench press, and four sets of pull-ups to failure, performed 3x per week. Both groups were instructed to maintain their BJJ training and avoid additional strength training. MST improved 1RM in the squat and bench press by 15 ± 9% ($p = 0.02$) and 11 ± 3% ($p = 0.03$), respectively, and CMJ height by 9 ± 7% ($p = 0.04$). Muscular endurance performance increased by 33 ± 33% in pull-ups ($p = 0.03$), 32 ± 12% in push-ups ($p = 0.03$), and 13 ± 13% in sit-ups ($p = 0.03$). Increases in RFD (35 ± 55%, $p = 0.13$) and PF (8 ± 9%, $p = 0.09$) did not reach significance. No improvements were apparent from BJJ training alone ($p > 0.05$). These findings suggest that MST is a potent approach to rapid improvements in maximal strength, power, and muscular endurance in active grapplers.

Keywords: MST; BJJ; physical preparation; combat sports; martial arts; allometric scaling

INTRODUCTION

Brazilian jiu-jitsu (BJJ) is a grappling-based combat sport that predominantly takes place on the ground, where the objective is positional control and submission of the opponent by way of a chokehold or joint lock. Early development of BJJ techniques focused on leverage and timing over strength and speed, reducing the reliance on physiological attributes. For the past few decades, BJJ has undergone a shift from focusing on self-defense to becoming a competitive sport. Under modern rulesets with a growing number of highly skilled competitors, strength and endurance have become increasingly important (24). A major part of the research effort to date has focused on technical, tactical, perceptual, and physiological aspects of BJJ combat (1, 30), and the characteristics of the athletes (4, 31), resulting in valuable insight into the physiological demands of the sport and the capabilities of its practitioners. There is, however, a dearth of training interventions exploring how to efficiently improve physical performance in this population while maintaining regular sport training.

Although BJJ training alone has been shown to increase strength and endurance in subjects with low baseline fitness levels (11, 33), data from representative athlete samples indicate a substantial potential for improvements in attributes such as maximal strength and aerobic endurance (4, 31). Interestingly, several studies report a discrepancy in maximal strength (9, 16) and power (15) between advanced and non-advanced BJJ athletes, indicating a relationship between strength and performance level. Similarly, competition success in grappling sports such as judo (18) and wrestling (8) has been associated with maximal strength and power, as well as muscular endurance. The apparent applicability of these aspects of strength in both upright and supine/semi-supine grappling suggest that targeting them specifically through training could benefit sport-specific performance.

Maximal strength training (MST) combines loads at a high fraction of one-repetition maximum (1RM) with maximal mobilization of force in the concentric phase (20). It is a widely used training approach with documented effect on force-generating capacity (i.e. maximal strength and rate of force development (RFD)) in various athlete populations and in turn sport performance (7, 21, 23). In fact, compared to conventional strength training at lower intensities, MST has been shown to induce approximately twice the increase in force-generating capacity (20). Since MST primarily targets neural adaptations (36), substantial improvements in maximal strength are possible without changes in body mass (m_b) (22). This is crucial in a weight class sport such as BJJ, where hypertrophy does not necessarily provide a performance advantage. Furthermore, MST may reduce local metabolic demand during exercise, leading to improved work economy (7).

While there is no official competition season for BJJ, athletes might spend 8 to 12 weeks leading up to a competition period preparing for the physiological, technical, and tactical demands of certain opponents and/or competition formats, and building a strength and endurance base (24, 27, 32). Given the limited duration of a typical pre-competition mesocycle, the magnitude of physiological change a grappler can achieve within a short time period is important. Thus, the aim of this study was to assess the impact of short-term MST on several parameters of strength in active grapplers. We hypothesized that performing MST as an accessory to regular BJJ training would induce significant improvements in maximal strength, muscular endurance, RFD, peak force (PF), and countermovement jump (CMJ) height.

METHODS

Experimental Approach to the Problem

A test protocol was developed to assess multiple parameters of strength. The following variables were measured: RFD and PF in the squat jump (SJ), CMJ height, 1RM in the parallel squat and paused bench press, pronated-grip pull-ups to failure, and time-restricted (1 minute) maximal repetitions in push-ups and sit-ups. Following baseline testing, the participating athletes were randomly allocated to either an MST group or control group (CON). The MST group performed three unsupervised MST sessions per week for four weeks (12 sessions) on non-consecutive days, consisting of four sets of four repetitions at ≥ 85% of 1RM in the parallel squat and paused bench press. Once ≥ 5 repetitions was achieved with a given load, the weight was increased by 2.5 kg. Additionally, they did four sets of pronated-grip pull-ups to failure at the end of each MST session. Three-minute intra-set rest intervals were prescribed. Both groups were instructed to avoid any additional resistance training and to maintain their regular BJJ training volume during the study. A questionnaire was used to assess BJJ training volume at baseline, with follow-up questions at the posttest to detect changes. Weekly check-ins throughout the study were used to promote adherence.

Subjects

The study sample comprised 14 male BJJ athletes (age: 30.6 ± 5.5 years; height: 184.2 ± 6.2 cm; m_b: 87.5 ± 12.0 kg) holding the rank of white (n = 4), blue (n = 5), or purple belt (n = 5), with 4.8 ± 4.5 years of BJJ experience, a tournament participation record of 7 ± 11, and a training volume of 8.1 ± 2.3 hours·week^{-1}. To limit the skill discrepancy between the participants, brown and black belts were ineligible for participation. Prior experience with resistance training was required to assure the ability to safely train at the prescribed intensity. Additionally, the subjects underwent a familiarization strength training session prior to the baseline measurements. The study was reviewed by the Regional Committee for Medical and Health Research Ethics and carried out in accordance with the latest Declaration of Helsinki. All subjects gave their written informed consent prior to participation.

Physical performance tests

Rate of force development and peak force

RFD and PF were assessed with SJ on a force platform (model 9286 AA; Kistler, Winterthur, Switzerland). The subjects were instructed to descend to a 90º knee angle, as determined by a universal goniometer, followed by a complete stop before a maximal effort jump. Despite training and testing to a parallel depth in the squat, the 90º knee angle was chosen to account for the challenges associated with RFD measurements in dynamic, multi-joint exercises. Importantly, deep squats have previously been shown to elicit improvements in the 90º SJ (19). Hands were kept at the hip throughout the movement. Three successful attempts were required. The highest recorded force was defined as PF and RFD was calculated as Δforce/Δtime between 10% and 90% of PF.

Vertical jump height

Vertical jump height was assessed with an unconstrained CMJ to a self-selected depth and the use of an arm swing for maximal performance. The same force platform as in the RFD and PF measurements was used. Maximal jump height was calculated from m_b-corrected force development with Bioware software v. 5.3.0.7 (Kistler, Switzerland). Three successful attempts were required, and the highest displacement of the center of mass was recorded for analysis.

Maximal strength

Maximal strength in the squat and bench press was assessed using an Olympic bar (20 kg) and weights (Eleiko Sport, Halmstad, Sweden). For the squat, the subjects were instructed to descend to the point where the femur was parallel to the ground, with the depth being controlled visually and with safety pins. The bench press was performed with a marked stop of ~1 second at the chest between the eccentric and concentric phase. Subjects had to keep the gluteal and scapula regions in contact with the bench, as well as the heel of the foot in contact with the floor, throughout the lift. For both lifts, subjects warmed up with the bar followed by 50% of their estimated 1RM. The load was increased progressively until muscular failure was reached or form was severely compromised. Increments were adjusted per the subject's perceived exertion, with the goal of reaching 1RM within five attempts.

Muscular endurance

One set of as many repetitions as possible of pull-ups with a pronated grip determined upper body pulling endurance. Each repetition started from a dead hang with the elbows fully extended and ended with the athlete lifting his chin above the bar. The athletes were instructed to train the same way they were tested. One-minute push-up and sit-up tests were used to assess pushing and abdominal endurance, respectively. The push-up procedure followed the recommendations of ACSM (34), with the low position being defined as the chest touching the recorder's flat hand on the ground. The subjects did a variation of the bent-knee sit-up, but with the recorder locking the subject's shins in place on a bench to achieve a 90° angle in the hip and knee joints. Then, the subjects were required to interlock their fingers behind their head and from the supine starting position bring their elbows up to their knees.

Allometric scaling

Measurements of physical capacities are typically presented in absolute and ratio scaled values. Ratio scaling assumes a linear relationship between the given performance metric and the denominator, e.g. m_b, and does not fully account for the influence of body size, which could result in biased assessments of performance, particularly in body size-heterogeneous populations. Thus, due to a large (41%) discrepancy in m_b in the present study sample, allometric relationships between outcome measures and m_b were established with the equation $y \cdot x^{-b}$, in which y is the performance variable, x the m_b, and b the allometric parameter. According to the theory of similarity (5), muscle strength is proportional to (∝) muscle crosssectional area, hence ∝ $m_b^{2/3}$. The same allometric parameter has been recommended for measurements of RFD (25). In strength tests where the m_b acts as the resistance, b = –0.33 ($m_b^{2/3} \cdot m_b^{-1}$) is suggested (25). Accordingly, in addition to absolute and ratio scaled values, allometric equations with these exponents were applied when appropriate.

Statistical analyses

Statistical analyses were performed using IBM SPSS version 24 (Chicago, IL, USA). Graphics were made using GraphPad Prism version 6 (San Diego, CA, USA). The Wilcoxon signed rank test was used to detect within-group changes from pre- to posttest. Between-group differences were assessed with the Mann-Whitney U test. Effect sizes (ES) were calculated as $r = \frac{\mathrm{z}}{\sqrt{\mathrm{n}}}$. Pearson product-moment correlation coefficients were used to determine the direction and relationship between relevant variables. Relative changes in outcome measures are presented as mean ± standard deviation (SD) and 95% confidence intervals (CI). Other data are presented as mean ± SD unless otherwise stated. Statistical significance was accepted at $p < 0.05$.

RESULTS

No adverse events occurred during the strength training or testing. The MST group reported 100% adherence to the intervention. Illness precluded one subject in CON from attending the posttest. Due to injuries unrelated to the study, one participant in the MST group was unable to complete the bench press training and was therefore excluded from the bench press and push-up measurements. Another participant in the MST group was unable to maintain his BJJ training volume, but completed the intervention. One participant in CON acquired a sport-related injury midway into the study period which had a slight impact on his BJJ training. All other participants maintained their BJJ training volume and completed all testing procedures.

---*Table 1*---

No differences in baseline measurements of age, m_b, rank, training experience and volume, and competitive experience were detected ($p > 0.05$). Apart from a discrepancy in CMJ, no differences in strength performance were detected between the two groups at baseline (table 1). At the posttest, m_b was unchanged in both groups ($p > 0.05$). Figure 1 illustrate the between-group differences in absolute strength variables.

---*Figure 1*---

Maximal strength training improved performance in the squat by 15 ± 9% (95% CI = 6.16, 23.14; $p = 0.02$; ES = 0.64), bench press by 11 ± 3% (95% CI = 7.22, 14.07; $p = 0.03$; ES = 0.64), and CMJ height by 9 ± 7% (95% CI = 2.01, 15.62; $p = 0.04$; ES = 0.54). Muscular endurance performance increased by 33 ± 33% (95% CI = 2.46, 63.65; $p = 0.03$; ES = 0.57) in pull-ups, 32 ± 12% (95% CI = 19.06, 44.31; $p = 0.03$; ES = 0.64) in push-ups, and 13 ± 13% (95% CI = 1.21, 24.51; $p = 0.03$; ES = 0.59) in sit-ups. Changes in RFD (35 ± 55%; 95% CI = -16.32, 85.64; $p = 0.13$; ES = 0.41) and PF (8 ± 9%; 95% CI = -0.49, 16.39; $p = 0.09$; ES = 0.45) did not reach significance. However, despite a lack of within-group differences in these outcome measures, ΔPF were significantly greater ($p = 0.04$) in the MST group than in CON. Additionally, the MST group achieved a higher mass-relative ($p = 0.05$) and scaled ($p = 0.02$) PF at the posttest compared to CON.

Except for a correlation with PF ($r = 0.672$; $p = 0.01$), RFD had no apparent relationship with other outcome measures. A strong tendency was observed between PF and squat 1RM ($r = 0.563$; $p = 0.056$), with significance being reached when normalizing to m_b ($r = 0.578$; $p = 0.05$). Bench press 1RM correlated with push-ups ($r = 0.714$; $p = 0.01$), sit-ups ($r = 0.723$; $p = 0.01$), and pull-ups ($r = 0.754$; $p = 0.01$). Similarly, increased squat 1RM was associated with improvements in sit-ups performance ($r = 0.624$; $p = 0.03$).

DISCUSSION

Over the past few years, several recommendations regarding the structure and contents of a pre-competition mesocycle for grapplers, including those incorporating heavy compound exercises (24, 27, 32). Accordingly, the present study sought to elucidate the effects of concurrent MST and BJJ training to assess the impact of this training modality in active grapplers. Quantifying the magnitude of physiological change that can be achieved by a grappler in the short-term, with minimal impact on sport training, can be of major benefit leading up to competition as part of the athlete's physical preparation. The main findings of the present study were that four weeks of MST significantly increased maximal strength, vertical jump height, and muscular endurance in active grapplers. Notably, neither vertical jump height or time-restricted muscular endurance were specifically targeted by the training program, yet both were substantially improved at the posttest. Brazilian jiu-jitsu training alone had no apparent effect on any outcome measure. These findings provide evidence that short-term MST is a potent training approach for improvements in neuromuscular performance in BJJ athletes.

Force-generating capacity is relevant in multiple phases of BJJ combat, such as taking the fight to the ground, passing, and submitting. While determining the exact impact of maximal strength on match outcome is challenging, the current literature points to a relationship between strength and performance level in several grappling sports (8, 9, 15, 16, 18). As hypothesized, MST produced substantial 1RM increases, with the squat improving by 15% and the bench press by 11%. Importantly, these improvements occurred with no change in m_b, which represents a major advantage in a weight class sport such as BJJ. Moreover, recent training data reveal that a large part of BJJ training consist of work at 85% of the athletes maximal heart rate (30). Accordingly, the present findings suggest a compatibility between MST and high-intensity sports.

An increase in maximal strength reduces the relative intensity of a given submaximal workload, which can have a discernable impact on aerobic endurance performance (7, 23). To determine if the increase in intramuscular efficiency previously observed following MST would benefit time-restricted local muscular endurance performance, athletes performed one-minute push-up and sit-up tests before and after the study period. Despite not doing a single repetition of either exercise as part of their training, the MST group improved their performance in these tests by 32% and 13%, respectively. Conversely, CON showed no improvement in push-ups while their sit-up performance decreased by 11%. As expected, the MST group also improved pull-up performance following the training period. Based on previous research on similar athletes (31), we anticipated a ~9RM pull-up baseline, which is equivalent to an intensity of approximately 75 - 80% of 1RM (26). Although this is a slightly lower intensity than that prescribed in MST, it is sufficient to produce strength improvements (29). Thus, we decided not to prescribe any additional pull-up resistance in the training intervention.

Despite some evidence to the contrary (10), neuromuscular performance has been shown to diminish following both single (2, 13) and multiple (12, 14) BJJ matches. To counteract neuromuscular fatigue, emphasis should be placed on increasing maximal strength and in turn fatigue resistance (23). The emphasis on groundwork in BJJ may result in less strain on muscles of the lower limbs (3) as opposed to more upright grappling (6). Unsurprisingly, there appears to be a relationship between CMJ and performance level in wrestling (8). Interestingly, a similar association has been observed in BJJ (15), despite consisting of comparably less work from the standing position. Following four weeks of MST, athletes in the present study increased their CMJ by 9%, which indicates improved power. This increase occurred with no specific jump training and is likely caused by the ballistic contractions during heavy squat training, and implies augmented force-generating capacity. Indeed, improvements in vertical jump height is not an uncommon finding following MST (21, 22). It should be noted that the use of an arm swing, which can improve jumping performance considerably, was allowed in the present study. Different test procedures have been used when assessing CMJ in BJJ athletes previously (10, 12, 13, 15), and direct performance comparisons should therefore be made with caution.

Rate of force development has become an increasingly popular and important outcome measure due to its sport-specific functional relevance (28), likely reflecting alterations in muscular characteristics, such as increased muscle size and type II muscle fiber proportion (28), and, perhaps most importantly, changes in efferent neural drive, i.e. firing frequency (including doublet discharges) and motor unit recruitment (28, 36). The ability to rapidly produce as much force as possible may be more important than producing maximal force in movements that does not allow time for maximal force production (> 300 ms) (35), which is often the case in grappling. Indeed, the relevance of lower-body power is well-documented in grappling sports (8, 15, 18). Increased RFD improves the athlete's ability to develop force under time constraint, thus impacting explosive actions, such as takedowns. Contrary to our hypothesis, changes in RFD following MST did not reach significance in the present athletes. This may have been due to one participant who, somewhat surprisingly, demonstrated a decrease in RFD from pre- to posttest despite improving in all other parameters, including the squat.

To avoid m_b bias, allometric exponents were used to calculate mass-independent performance values in measurements that have non-linear relationships with body size. Resultantly, these performance values can be used to compare athletes from different weight classes. The weight classes in the present sample ranged from lightweight to ultra heavyweight, necessitating some form of control of the size differences to reasonably compare the strength measurements. It is critical to consider the relationship between strength and size in studies using body size-heterogeneous study samples. Furthermore, allometric scaling might also be advisable in samples comprised of athletes from the same weight class in cases of large discrepancies in body composition. While normalizing strength to m_b appears appropriate in relatively lean populations, other denominators, e.g. fat-free mass, or lower m_b scaling exponents might be more relevant in populations with > 20% body fat (17).

Limitations to the present study include high variability in certain outcome measures, particularly related to force platform data. Alternative assessments of RFD and PF include adding load and using safety pins to determine depth, which would have made the attempts easier to standardize and may have reduced variability. Additionally, supervising each training session could have impacted aspects such as training intensity and the rate of progression, and ultimately resulted in a larger MST response. Lastly, using time-restricted assessments of muscular endurance may misrepresent actual performance due to not finding the appropriate timing to maximize the number of repetitions. Accordingly, the reduction in sit-up performance in CON is likely more a result of time-mismanagement that actual reduced muscular endurance. In future studies, extended time limits or alternative assessments should be considered.

In conclusion, concurrent MST and BJJ training produced marked improvements in strength performance in active grapplers, including in parameters not specifically targeted by the training intervention. Maximal strength training represents a potent approach to rapid improvements in maximal strength, power, and muscular endurance in active grapplers.

PRACTICAL APPLICATIONS

This is the first study that explores the effects of MST as an accessory to BJJ in trained grapplers. The present findings indicate the magnitude of physiological change a grappler can expect in a short timespan using near-maximal training loads and linear progression. The short period over which this progress was made highlights the applicability of this training approach in a sport with irregular competition schedule and rulesets such as BJJ. Although the impact of force-generating capacity on competition outcome in BJJ has yet to be established, the importance of strength in grappling sports is supported by the current literature. The squat and bench press are considered essential compound exercises for athletes in general, but other movements might be preferable to certain athletes and in certain sports. Importantly, the principles of MST, i.e. loads ≥ 85% of 1RM and maximal intended velocity in the concentric phase, are applicable to other exercises than those used in the present study.

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FIGURE LEGENDS

Figure 1 Relative changes in strength performance from pre- to posttest

*Data are presented as mean ± standard error. MST, maximal strength training; CON, control; RFD, rate of force development; PF, peak force; CMJ, countermovement jump; * significant difference within group ($p < 0.05$); # significant difference between groups ($p < 0.05$). ## significant difference between groups ($p < 0.01$).*

Figure

Click here to download Figure Figure 1.tif

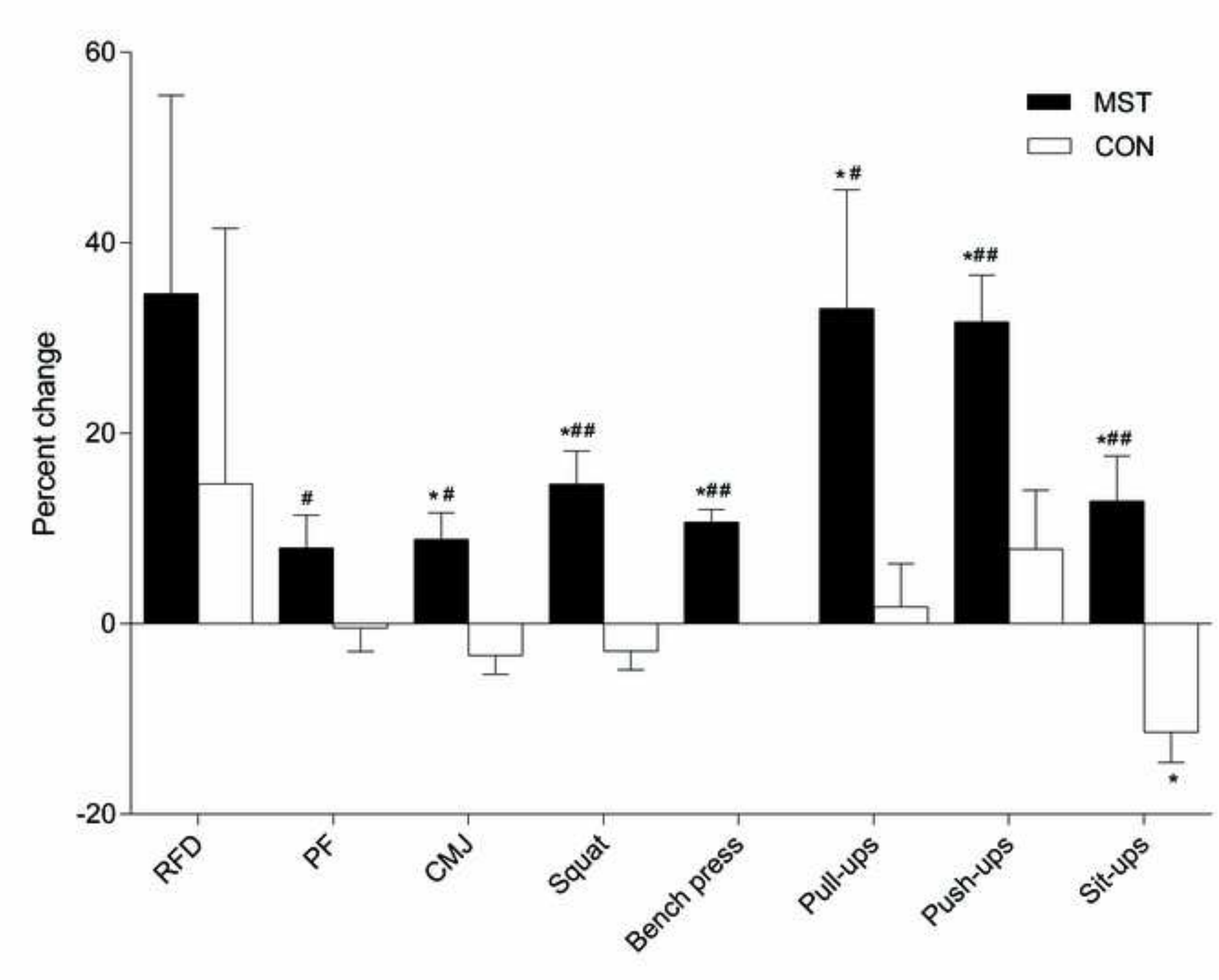

TABLE LEGENDS

Table 1 Changes in strength performance from pre- to posttest

	MST		CON	
	Pretest	**Posttest**	**Pretest**	**Posttest**
RFD				
$N \cdot s^{-1}$	8543.3 ± 5466.0	10039.5 ± 5160.6	7306.1 ± 2088.7	7424.2 ± 1559.9
$N \cdot s^{-1} \cdot m_b^{-1}$	95.8 ± 64.3	113.9 ± 64.6	87.3 ± 31.9	85.5 ± 17.9
$N \cdot s^{-1} \cdot m_b^{-0.67}$	421.5 ± 277.9	498.9 ± 273.5	375.4 ± 126.3	372.1 ± 72.4
PF				
N	2119.7 ± 350.2	2269.9 ± 302.7$^{\#}$	1985.7 ± 279.8	1971.7 ± 255.6
$N \cdot m_b^{-1}$	23.7 ± 2.8	25.4 ± 2.9†	22.8 ± 1.7	22.7 ± 1.3
$N \cdot m_b^{-0.67}$	104.3 ± 13.6	111.7 ± 12.3$^{\dagger\#}$	99.3 ± 4.9	98.7 ± 2.1
CMJ (cm)	48.2 ± 8.0†	52.3 ± 8.6*$^{\#}$	53.8 ± 4.0	52.1 ± 5.2
Squat				
1RM (kg)	120.0 ± 17.6	137.1 ± 19.8*$^{\#\#}$	124.2 ± 18.0	122.0 ± 23.9
1RM ($kg \cdot m_b^{-1}$)	1.4 ± 0.2	1.5 ± 0.2*$^{\#\#}$	1.4 ± 0.3	1.4 ± 0.3
1RM ($kg \cdot m_b^{-0.67}$)	5.9 ± 0.9	6.8 ± 1.0*$^{\#\#}$	6.3 ± 0.9	6.0 ± 1.1
Bench press				
1RM (kg)	91.1 ± 14.0	97.9 ± 13.5*$^{\#\#}$	86.7 ± 21.8	86.7 ± 21.8
1RM ($kg \cdot m_b^{-1}$)	1.0 ± 0.2	1.1 ± 0.2*$^{\#\#}$	1.0 ± 0.2	1.0 ± 0.2
1RM ($kg \cdot m_b^{-0.67}$)	4.5 ± 0.8	4.8 ± 0.6*$^{\#\#}$	4.3 ± 0.8	4.3 ± 0.8
Pull-ups				
RM (n)	10 ± 6	12 ± 5*$^{\#}$	10 ± 4	10 ± 4
RM ($n \cdot m_b^{-1}$)	0.1 ± 0.1	0.1 ± 0.1*	0.1 ± 0.1	0.1 ± 0.1
RM ($n \cdot m_b^{0.33}$)	42 ± 24	51 ± 21*	42 ± 16	43 ± 17
Push-ups				
RM ($n \cdot min^{-1}$)	29 ± 6	36 ± 7*$^{\#\#}$	29 ± 11	31 ± 11
RM ($n \cdot m_b^{-1} \cdot min^{-1}$)	0.3 ± 0.1	0.4 ± 0.1*$^{\#}$	0.3 ± 0.1	0.4 ± 0.1
RM ($n \cdot m_b^{0.33} \cdot min^{-1}$)	126 ± 24	159 ± 28*$^{\#\#}$	128 ± 52	136 ± 53
Sit-ups				
RM ($n \cdot min^{-1}$)	32 ± 10	35 ± 9*$^{\#\#}$	36 ± 8	32 ± 6*
RM ($n \cdot m_b^{-1} \cdot min^{-1}$)	0.4 ± 0.1	0.4 ± 0.1*$^{\#\#}$	0.4 ± 0.1	0.4 ± 0.1*
RM ($n \cdot m_b^{0.33} \cdot min^{-1}$)	140 ± 42	155 ± 35*$^{\#\#}$	155 ± 30	137 ± 27*

*Data are presented as mean ± standard deviation. MST, maximal strength training; CON, control; RFD, rate of force development; PF, peak force; CMJ, countermovement jump; 1RM, one-repetition maximum; m_b, body mass; RM, repetition maximum; * significant difference within group ($p < 0.05$); † significant difference between groups ($p < 0.05$); $^{\#}$ significant difference between groups from pre- to posttest ($p < 0.05$); $^{\#\#}$ significant difference between groups from pre- to posttest ($p < 0.01$).*