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Section: Original Investigation

Article Title: The Neuromuscular Qualities of Higher and Lower-Level Mixed Martial Arts Competitors

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The neuromuscular qualities of higher and lower-level mixed martial arts competitors

An Original Investigation

By

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ABSTRACT

Purpose: To determine whether the maximal strength, impulse and power characteristics of competitive mixed martial arts (MMA) athletes differ according to competition level. **Methods:** Twenty-nine male semi-professional and amateur MMA competitors were stratified into either higher-level (HL) or lower-level (LL) performers on the basis of competition grade and success. The one-repetition maximum (1RM) squat was used to assess lower body dynamic strength, while a spectrum of impulse, power, force and velocity variables were evaluated during an incremental load jump squat. Additionally, participants performed an isometric mid-thigh pull (IMTP) and 1RM bench press to determine whole-body isometric force and upper body dynamic strength capabilities, respectively. All force and power variables were expressed relative to body mass (BM). **Results:** The HL competitors produced significantly superior values across a multitude of measures. These included 1RM squat strength (1.84 ± 0.23 vs 1.56 ± 0.24 $kg \cdot BM^{-1}$; P=0.003), in addition to performance in the incremental load jump squat that revealed greater peak power (P=0.005-0.002), force (P=0.002-0.004) and velocity (P=0.002-0.03) at each load. Higher measures of impulse (P=0.01-0.04) were noted in a number of conditions. Average power (P=0.002-0.02) and velocity (P=0.01-0.04) at all loads in addition to a series of rate-dependent measures were also superior in the HL group (P=0.005-0.02). The HL competitors' 1RM bench press values approached significantly greater levels (P=0.056), while IMTP performance did not differ between groups. **Conclusions:** Maximal lower body neuromuscular capabilities are key attributes distinguishing HL from LL MMA competitors. This information can be used to inform evidenced-based training and performance monitoring practices.

Key words: Combat sports; jump squat; athletic performance; contact sports; force-velocity relationship

INTRODUCTION

Mixed martial arts (MMA) is a weight-classed structured combat sport that contains both amateur and professional competition tiers. This sport is characterised by repeated collisions and an extended intermittent activity pattern, driven by periods of high intensity action followed by lower intensity work and occasional pauses in activity.[1] This leads to the potential for a complex physiological profile whereby an array of neuromuscular and conflicting endurance adaptations could be required to compete successfully. Because of this, and a paucity of research investigating MMA athletes, it is unknown whether expressions of maximal strength, impulse and power define this sport's superior competitors. The determination of the trainable qualities which underpin higher-level performance may allow sports scientists and performance coaches to effectively design training plans that target the physiological adaptations most likely to influence performance enhancement.[2] Furthermore, this information could provide a framework for identifying those athletes in alternate sports who already possess these attributes.[3]

It has been reported that maximal strength and power often distinguish superior competitors in combat sports.[4] However, the increased bout durations scheduled in MMA when compared to these alternate sports, in addition to differing technical demands, limit the conclusions that can be drawn from such findings. Furthermore, despite the notion that impulse is the primary factor influencing many athletic actions,[5] there is little research investigating this function in the sport science literature. This limits our understanding of its contribution to competitive success in a given sport. Taken together, until the nature of the relationship between maximal neuromuscular expressions and competition performance is explored in MMA, the association between these capabilities and success in this sport is speculative.

The purpose of this study was to compare the maximal strength, impulse and power attributes of higher- and lower-level MMA competitors to determine the variables that hold the

most importance to performance in the sport. If differences are revealed, the findings of this investigation can provide valuable direction for strength and conditioning coaches and sports scientists in the design of training and monitoring practices for MMA athletes.

METHODS

Subjects

Twenty-nine male competitive semi-professional and amateur MMA athletes were recruited to take part in this study. Eligibility required that all participants had a verifiable competition record through a reputable database previously consulted in the literature (www.sherdog.com),[6] were currently participating in MMA specific training and had no injuries limiting involvement in resistance training activities. Subjects were stratified into either higher (HL) (*N*=15, body mass [BM] = 79.8 ± 10.46 kg; age = 29.5 ± 2.2y) or lower-level (LL) (*N*=14, BM = 82.3 ± 12.5 kg; age = 26.6 ± 7.95y) groups based upon professional or amateur competition status and success. Specifically, the HL group included only semi-professional athletes with a professional record of > 50% wins (professional bouts = 10.6 ± 8.3; total bouts = 14.33 ± 7.18; years actively competing in MMA = 5.87 ± 2.36; years undertaking MMA specific training = 6.07 ± 2.21), while fighters with a professional winning record of ≤ 50%, and amateur competitors were allocated to the LL strata (professional bouts = 1.36 ± 2.87; total bouts = 5.64 ± 4.55; years actively competing in MMA = 3.11 ± 1.94; years undertaking MMA specific training = 4.36 ± 2.59). All participants were made aware of any risks associated with involvement and provided their written informed consent. This experiment was approved by the University of Queensland's research ethics committee.

Experimental design

The testing session was initiated with a standardised dynamic stretching protocol. To assess lower-body maximal power capabilities, the incremental load jump squat (JS) was

performed using non-randomised progressively increasing[7] relative loads: +0% of BM (no additional weight added), +25%, +50%, +75% and +100% of BM, [8] while the squat jump (SJ) was executed using +0% of BM only. A 20-minute lower body recovery period followed, during which the assessment of 1 repetition maximum (1RM) bench press was undertaken. The 1RM back squat to a depth resulting in a knee angle of <90 degrees of flexion was then performed. Following this, maximal isometric force was assessed via the isometric mid-thigh clean pull (IMTP), using a custom built portable apparatus.[9]

Data acquisition procedures

Incremental load jump squat and unloaded squat jump

Trials were conducted utilising a doweling rod in the 0% condition and the unrestrained bar with according weight plates in the loaded conditions. Three non-continuous JS for maximal height at a self-selected depth[10] were performed against each prescribed load with the repetition containing the highest peak power for each condition used for analysis. A minimum of 3 minutes of passive recovery was allowed between each set. The SJ (no countermovement) was performed in the unloaded condition only. In this, the athlete descended to a depth resulting in 90 degrees of knee flexion, as measured by goniometry, where they held for 3s. The athlete was then instructed to jump for maximal height.[11] If a countermovement was visually noted or determined by careful examination of the position-time tracing, the test was repeated with the above methods until a valid attempt was made.

Displacement-time data was collected via a linear position transducer sampling at 100Hz (resolution 0.076mm, Musclelab, Ergotest Technology, Norway). Force was attained via double-differentiation and integrated with the velocity-time curve to generate a predicted power-time trace via native software (MuscleLab V8.26, Ergotest Technology, Norway). Although the use the second order derivative of displacement-time data to calculate force is

susceptible to an increased likelihood of error when compared to kinetic or combined methods,[12] such techniques are based on correct mathematical principles and are consistently reported as highly reliable.[13] Shank mass of 12% was subtracted from the system mass for all calculations of force.[8, 12] Data was then extracted and a spectrum of conventional and rate-dependent variables were acquired via a custom designed Matlab script (The Mathworks, Inc., Natick, MA) (Table 1). Such rate-dependent measures obtained during loaded jump squats have shown acceptable reliability with analogous instrumentation.[14, 15] Power ($W \cdot kg^{-1}$), force ($N \cdot kg^{-1}$) and impulse ($m \cdot s^{-1}$) values were then expressed in relative terms to the athletes BM.

1 repetition maximum bench press and back squat

Well documented 1RM procedures[16] were followed for the back squat and bench press assessment. In the 1RM back squat test, a depth resulting a knee angle of <90 degrees of flexion was required for a valid attempt. A successful effort was confirmed through 2 dimensional motion analysis (HL: 85.1 ± 3.36°, LL: 86.4 ± 2.68°) (Kinovea, V0.8.15). To consider both conventional and alternate normalisation procedures, the final result for the bench press and back squat was then ratio ($kg \cdot BM^{-1}$) and allometrically scaled (load · (body mass $^{0.67})^{-1}$).[17]

Isometric mid-thigh pull

Following a 10 minute recovery period, maximal whole-body isometric force was assessed by a portable, open chain IMTP.[9] Participants were positioned in the IMTP with hip and knee angles at 144.13°±5.52 and 143.19°±6.75° respectively,[18] and procedures outlined by James et al. [9] were undertaken. The greatest force value during the 5s maximal effort was taken and expressed relative to BM ($N \cdot kg^{-1}$) and allometrically scaled (load · (body mass $^{0.67})^{-1}$) for analysis.

Statistical analysis

An independent t-test was used to determine the presence of differences between the two competition groups across outcome measures. The alpha level was set at $P \leq 0.05$ and considered statistically significant. To compare the magnitude of practical difference between groups, Cohen's *d* effect size (ES) values were calculated. Thresholds of 0.2-0.6, 0.61-1.2 and 1.21-2.0 were used to describe small, moderate and large practical differences respectively.[19] To compare the strength of association between measures in each group, Pearson correlations were calculated across three sets of comparisons. The first two included all non-JS performance measures alongside: 1) all JS variables at +25% and, 2) all JS variables at 100%. The third series consisted of all non-ballistic measures in addition to peak power at +0% of the JS, and SJ peak power. A Fisher's r to z transformation was subsequently performed to determine the presence of a difference between the two groups in any matching pairs of significant correlations revealed from the initial analysis. Correlations were classified as: 0-0.1: trivial, 0.11-0.3: small, 0.31-0.5: moderate, 0.51-0.7: large, 0.7-0.9: very large, and >0.9: extremely large.[20] To compare the predictive ability of impulse and power on group membership, a binary logistic regression was employed (1= HL, 0 = LL). The impulse and maximal power measure with the highest magnitude of effect (ES) were entered into this model following collinearity diagnostics. A standardized beta coefficient was then calculated to compare the impact of a one standard deviation (SD) increase in the two covariates.[21] The data are presented as mean ± the SD. Primary analysis was performed using the Statistical Package for Social Sciences (version 22, IBM, New York, 216 USA). Effect size statistics in addition to the standardized beta coefficients from the logistic regression were calculated in Microsoft Excel 2013 (Microsoft Corporation, Washington, USA).

RESULTS

Ratio scaled lower body dynamic strength in the 1RM back squat was significantly greater (1.84 ± 0.23 vs 1.56 ± 0.24 kg·BM^{-1}; *P* =0.003; ES = 1.04) amongst the HL group. This finding also held true when allometrically scaled (*P* = 0.001; ES=1.11). The JS revealed higher levels of net impulse under loads of +0%, +25% and +50%, in addition to impulse at 300ms across all measured loads in the HL group (Figure 1 A and B). Superior levels of peak power, velocity and force in each condition were found in these athletes also (Figure 2 A, B and C). Similarly, significantly greater force was produced at peak power throughout the force-velocity curve (Figure 3) amongst the HL competitors, while differences between groups in average power and velocity also achieved significance for all jump conditions (Figure 4 A and B). Peak rate of power development (RPD) across all measured loads was significantly greater in the HL group, however only the +50% load reached significantly increased levels for the measure of average RPD (Table 2). Non-significant differences were revealed between groups in time-to-peak variables, other than TTPF at +50% loading (Table 3).

Peak power (HL = 44.45 ± 7.54 vs LL = 38.47 ± 6.74 W·kg^{-1}; *P* = 0.03; ES=0.78) and peak velocity (HL = 3.06 ± 0.33 vs LL = 2.81 ± 0.33 m·s^{-1}; *P* = 0.05; ES= 0.72) in the SJ reached significantly greater levels amongst the HL competitors, while no differences were found between groups in the reactive strength index (HL =14.91 ± 7.32 vs LL = 10.10 ± 6.53 W·kg^{-1}; *P* = 0.07; ES=0.66). Relative 1RM bench press strength (HL = 1.21 ± 0.18 vs LL=1.07 ± 0.20 kg·BM^{-1}; *P* = 0.06; ES=0.71) and relative peak force as assessed in the IMTP (HL=25.87 ± 3.98 vs LL=26.41 ± 5.34 N·kg^{-1}; *P* = 0.76; ES= -0.12) did not differ between the groups. Likewise, no differences between groups were found when 1RM bench press (*P* = 0.08; ES= 0.66) and IMTP peak force (*P* = 0.68; ES= -0.16) were expressed as allometrically scaled values.

Within the first series of correlation comparisons (all non-JS measures in addition to all variables from the JS +25% condition), HL competitors produced 19 significant, very large relationships compared to 36 found in the LL group. When correlations were examined with +100% measures in place of the lighter condition (series 2), 27 and 36 significant relationships of this magnitude were noted in the HL and LL group respectively. The final series of correlation comparisons (peak power at 0%, SJ peak power in addition to all non-ballistic variables) revealed significant relationships between IMTP and SJ peak power (r = 0.51) in the HL group, while bench press and squat performance were significantly correlated in the LL competitors (r = 0.63). Table 4 presents Fisher's z comparisons for series 1 and 2. No matching pairs of significant relationships were present to compare across the third series of correlations. Peak power (+0%) and impulse at 300ms (+50%) were found to have the greatest ES of each attribute (peak power + 0% = 1.01, impulse at 300ms +50% = 0.95) and were therefore entered into the logistic regression following collinearity diagnostics (r = 0.317, P = 0.10). Only the power variable significantly contributed to the prediction of group membership (standardized β = 0.348, Wald = 5.322, P = 0.02), while the measure of impulse had a smaller, non-significant contribution (standardized β = 0.302, Wald = 3.452, P = 0.06). The model achieved a 75.9% classification accuracy.

DISCUSSION

The primary finding of this investigation is that a multitude of maximal lower-body neuromuscular performance measures are significantly enhanced in HL MMA athletes compared to LL competitors. This is represented by differences in dynamic strength, in addition to a spectrum of impulse, power, force and velocity variables derived from maximal ballistic expressions. Such clear distinctions in these physiological attributes highlight the crucial role they play in competition performance.

Based upon the proximal to distal sequencing of many sporting actions, it is not unexpected that lower-body measures are where the greatest differences between the two groups were found. The superior 1RM squat strength in the HL group provides an indication that high force actions represent a vital component of MMA combat. This can be seen during many grappling encounters whereby the mass of the opponent must be manipulated to achieve a more advantageous position. Additionally, positive relationships have been reported between lower-body strength and punching acceleration amongst high-level karate competitors [22], highlighting the importance of this quality to striking attacks also. The ratio scaled 1RM squat strength of both the HL (1.84 ± 0.23 $kg \cdot BM^{-1}$) and LL (1.56 ± 0.24 $kg \cdot BM^{-1}$) groups in this study were considerably greater than what has been reported previously amongst a group of amateur MMA competitors only (1.40 ± 0.1 $kg \cdot BM^{-1}$), to a very large (ES=2.48) and moderate (ES=0.87) magnitude respectively.[23] This difference is most likely due to the predominantly higher calibre competitors utilised in the present study, and provides further evidence of an increase in lower-body strength in accordance with competition level in this sport.

The greater levels of lower-body impulse displayed by the HL group support the notion that this quality is a primary factor influencing performance.[5] These enhanced capabilities across unweighted and loaded testing conditions reflect the demands of MMA activity, which require expressions of impulse in both higher- and lower-force situations. In particular, a swift and technical repositioning of the athlete's centre of mass in concert with an impulse application into the ground results in horizontal velocities in the direction of the opponent when entering many takedown attempts. Once this distance has been closed and the athlete-opponent become a single system, forces must be precisely applied to shift the opponent off their base of support to complete the manoeuver. Consistent with these present findings, athletes who perform better in similar tasks (change of direction and agility) are reported to produce a higher propulsive impulse.[24] In addition to many takedown techniques, strikes require forces

generated by the lower body that allow the attack to land in the desired location using the window of time available. In both these examples, the opponent can apply swift and precise changes in position to evade, then counter, such attacks. Underpinning these effective applications of impulse is the optimization of stretch-shortening cycle and neuromuscular factors within an anticipated epoch.[5]

An examination of all JS load-power, -velocity and -force profiles revealed a significant upwards translation to increased values across all conditions in the HL group. Alongside this were practically relevant differences for all such measures including ES of 1.01 (95% CI = 0.34 to 1.67), 1.10 (95% CI =0.45 to 1.74) and 1.13 (95% CI = 0.48 to 1.78) for the conditions containing the highest peak power (+0%), peak force (+100%) and peak velocity (+0%) respectively. When taken together with the HL group's greater application of force at a given velocity throughout the spectrum (Figure 3), these data are in agreeance with those of impulse which strongly indicates that MMA combat requires maximal neuromuscular expressions in both high force and high velocity conditions. This includes grappling encounters where considerable forces are utilised to overcome the inertia of the opponent's mass. Consequently, the velocity demands increase and in some cases either the opponent or both fighters may then enter free space, thus becoming a projectile and further increasing the velocity of this action. Rapid expressions of force in velocity dominant conditions are seen in striking techniques, and when executing rapid displacements such as closing the distance between an opponent to clinch or apply a takedown technique. In these actions there is minimal resistance to overcome (and therefore lower force demands) allowing for an increase in velocity of movement.

The higher values produced by the HL group in peak RPD in all loading conditions, and average RPD with +50% and +75% loading demonstrates that the rate at which power can be expressed is of notable importance in MMA. Such findings are indicative of the nature of many athletic efforts whereby only brief windows of time are available to complete a

manoeuver.[25, 26] The finding that HL competitors were successful in achieving higher peak force in a significantly shorter time from the initiation of the action than the LL group in the +50% condition lends further support to this. However, when considered in concert with the other findings of this investigation, the lack of significant differences between groups in the remaining time-to-peak measures suggests that throughout the loaded ballistic efforts both groups continued to increase power, force and velocity for similar durations, while it is the magnitude and rate at which these functions are produced that define superior MMA performance.

The results of this investigation reveal that not all measures are significantly greater in the HL competitors. No differences were present in upper body maximal strength between groups and suggests that this quality is not as important as those of the lower body, which primarily generates the forces to be transferred along the kinetic chain. However, these values did approach significance (P=0.056) and an ES of 0.71 was present, indicating that upper body strength of the HL group was practically greater to a moderate magnitude in these athletes. These findings are similar to what is generally reported in combat sport literature, whereby upper body strength level did not significantly denote more successful competitors in either grappling or striking sports [4]. Although García-Pallarés et al. [27] reported increased levels of this attribute in elite (n=46) versus amateur (n=46) wrestlers, this was influenced by the considerably larger sample size than what is commonly seen in combat sport investigations. Maximal isometric force capabilities as assessed by the IMTP did not statistically differ between groups, nor were any practical differences present (ES=-0.012). Similar standing, multi-joint maximal isometric strength assessments have effectively described more successful combat sport competitors in some, but not all studies [4]. It may be such that the high forces that greatly influence success in MMA combat are still predominantly dynamic in nature, or that the position assumed in the test may not reflect the most decisive positions in this sport.

However, the values produced by this combined cohort (2032 ± 366 N, 26.1 ± 4.59 N·kg^{-1}) are markedly higher than those reported for resistance trained males (1657 N, 21.3 N·kg^{-1}) for the identical test [9] and suggests that peak force assessed via the IMTP does contribute to MMA performance.

The fewer and smaller correlations across the JS variables in the HL group suggests that these are indeed discrete measures of differing maximal neuromuscular attributes within MMA competitors of this calibre. As such, it appears as though as an athlete's maximal power, strength level and MMA performance increases, more specific adaptations occur to the neuromuscular system in response to training in this sport. This is supported by the finding that weaker individuals display non-specific adaptations to a power training intervention, while a more specific response is elicited amongst those who are stronger.[16] Taken together, this indicates that the temporal aspects of power expression become increasing more relevant to MMA performance with higher competition levels.

The presence of more consistent training within the HL group is likely responsible for the significant relationship found between isometric peak force and SJ peak power within this strata and further highlights the well documented relationship between strength and power qualities.[28] However, a unique finding amongst these correlations is an absence of relationship between maximal power measures in the JS and relative back squat performance or isometric peak force in either group. This might be explained by a lack of overall training homogeneity within the groups, with individual athletes at differing stages of their respective training plans.[29, 30]

Recent discussions have suggested a primary role for impulse over expressions of maximal power in influencing athletic performance.[5] In contrast to this, the logistic regression results in this present investigation identified only maximal power as a significant contributor to the prediction of HL MMA performance. Although the impulse variable in the model

approached significance (P = 0.06), an examination of the standardised beta coefficient revealed a lower contribution to the predictive capacity of the model when compared to the power variable. As such, these findings indicate that an increase in peak power has a greater positive influence on predicting HL MMA group membership than does an equivalent increase in impulse when controlling for the alternate factor.

Practical applications

Based upon these findings, MMA athletes should aim to enhance maximal relative lower body strength and neuromuscular expressions throughout the loading spectrum, as these are the attributes most associated with competition success. It is recommended that weaker fighters (1RM squat <1.6 $kg \cdot BM^{-1}$) emphasise heavy strength training to effectively develop these qualities.[16] Stronger athletes can accompany heavy strength training with an increased focus on higher velocity actions such as Olympic lifts and their variants, plyometrics and jump squats utilising differing resistances. To a lesser but still relevant extent, upper body strength should also be targeted. Measures derived from the squat and incremental load jump squat can be used for valid performance testing and monitoring of MMA competitors.

Conclusion

This investigation is the first to describe the physiological qualities of HL versus LL MMA competitors, and to the authors' knowledge the only study to compare impulse expressions in addition to the lower-body load-power, load-force and force-velocity relationships between combat athletes of differing success levels. HL MMA athletes produce superior maximal lower body expressions in both high-force and high-velocity conditions than LL competitors, which highlights the vital role of these qualities to the sport. Additionally, although impulse is of great importance, these findings indicate that maximal power is a

superior predictor of HL MMA performance. Taken together, these data provide guidance for evidenced based training interventions, physiological testing and performance diagnoses

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Conflicts of interest

The authors have no conflicts of interest relevant to this investigation.

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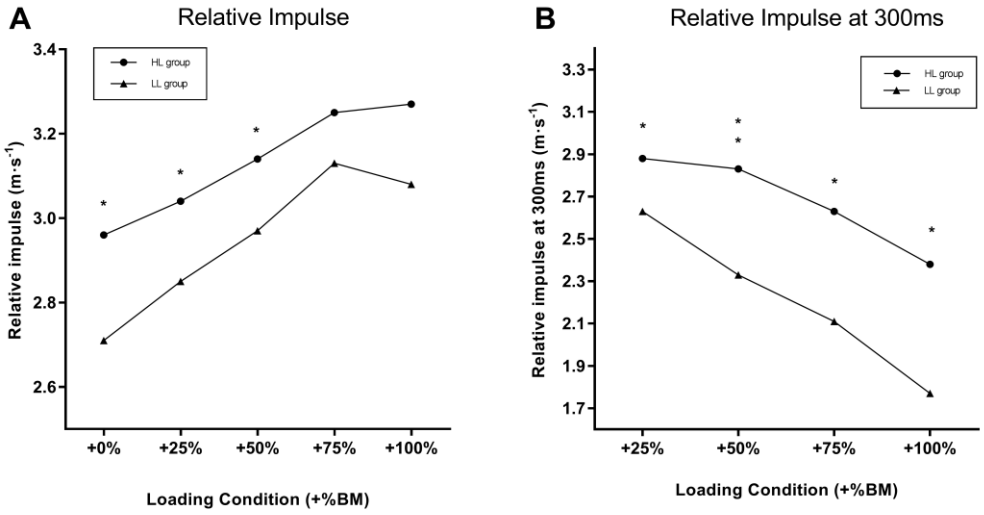

Figure 1: Between group differences in relative concentric phase impulse (A) and relative concentric phase impulse at 300ms (B).

**Significance at ≤0.01.

*Significance at ≤ 0.05.

HL: Higher-level group; LL: Lower-level group; BM: Body mass.

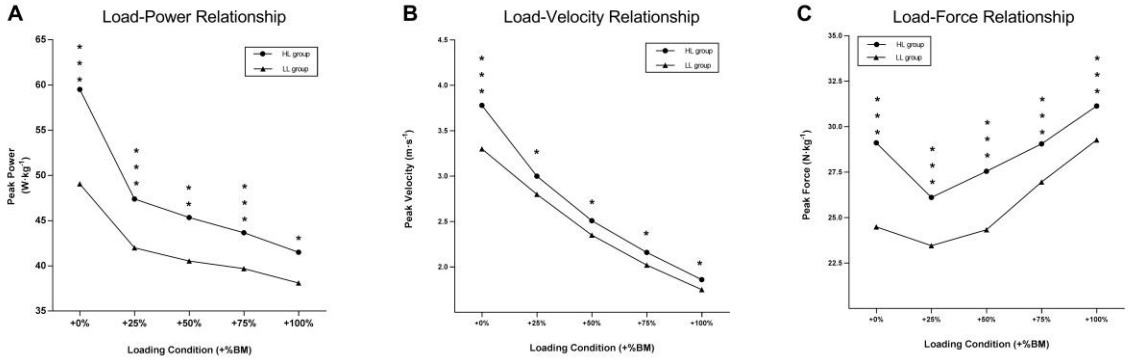

Figure 2: Between group differences in the load-power (A), load-velocity (B) and load-force (C) relationships for the jump squat.

***Significance at ≤0.005.

**Significance at ≤0.01.

*Significance at ≤ 0.05. HL: Higher-level group; LL: Lower-level group; BM: Body mass.

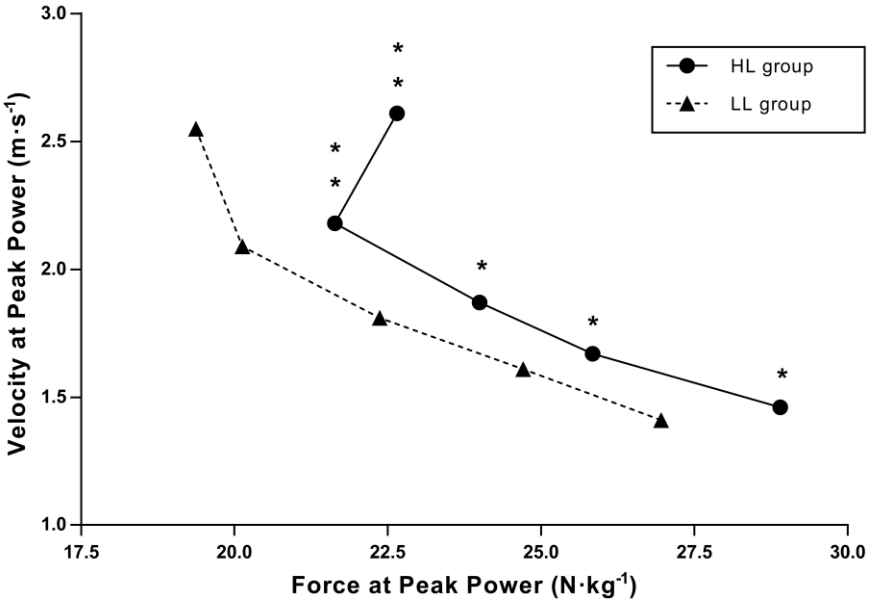

Figure 3. Between group differences in the force-velocity relationship for the jump squat. Asterisks indicate significantly different force at peak power between groups.

**Significance at ≤0.01.

*Significance at ≤ 0.05.

HL: Higher-level group; LL: Lower-level group.

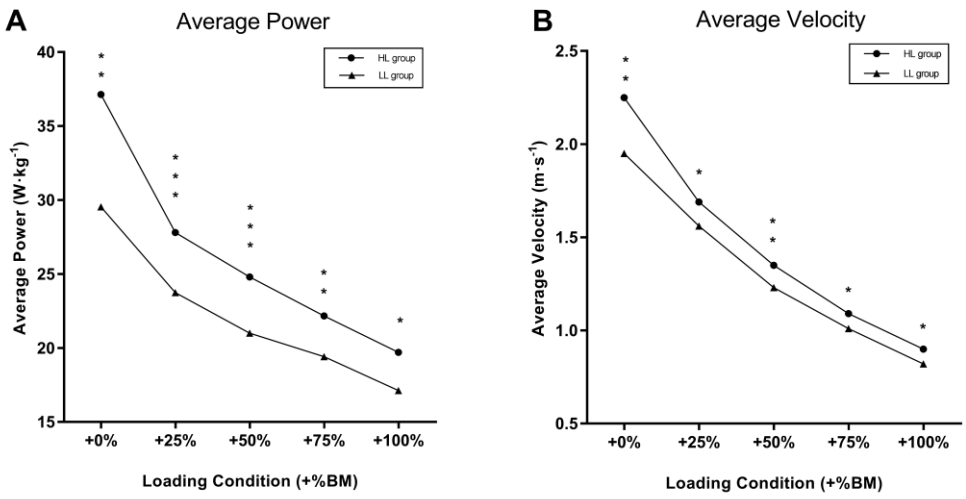

Figure 4. Between group differences in average power (A) and average velocity (B) across all loading conditions in the jump squat.

***Significance at ≤0.005.

**Significance at ≤0.01.

*Significance at ≤ 0.05. HL: Higher-level group; LL: Lower-level group; BM: Body mass.

Table 1. Measures derived from the incremental-load jump squat. Rate-dependent variables were calculated across the loaded conditions only.

	Measure	Calculation
Conventional		
	Peak power, -velocity and –force	The greatest instantaneous respective value achieved throughout the action
	Average power and -velocity	The beginning of the concentric phase until the frame in which the respective peak was reached
	Net impulse	The integral of force, above that of system weight, and time from the lowest position on the displacement-time curve until the point where net force dropped below that of system weight
	Reactive strength index	Jump squat (+0%) peak power minus squat jump peak power
Rate-dependent		
	Average rate of power development	The change between minimum and maximum values during the action
	Peak rate of power development	20ms moving average between minimum and maximum values throughout the action
	Impulse at 300ms	The integral of force, above system weight, and time over a 300ms period from the lowest displacement position
	Time-to-peak power, -velocity and -force	The time elapsed (s) from the initiation of the countermovement until the greatest respective value was reached.

Table 2. Comparisons of rate of power development (RPD) measures between groups

	HL group	LL group	*P*	ES
Peak RPD ($W \cdot kg^{-1} \cdot s^{-1}$)				
+25%	352.68 ± 84.51	264.46 ± 68.19	0.005***	1.14
+50%	274.04 ± 99.14	198.75 ± 34.68	0.01**	1.00
+75%	217.61 ± 54.02	178.50 ± 28.30	0.02*	0.90
+100%	195.34 ± 37.08	166.22 ± 24.79	0.02*	0.92
Average RPD ($W \cdot kg^{-1} \cdot s^{-1}$)				
+25%	184.18 ± 46.02	157.15 ± 50.25	0.14	0.56
+50%	143.03 ± 51.28	104.82 ± 25.73	0.02*	0.93
+75%	107.84 ± 43.53	84.91 ± 13.67	0.07	0.70
+100%	83.31 ± 23.65	69.73 ± 15.96	0.08	0.67

***Significance at ≤0.005. **Significance at ≤0.01. *Significance at ≤ 0.05. HL: Higher-level group; LL: Lower-level group; ES: Effect size.

Table 3. Comparisons of rate of time-to-peak measures between groups

	HL group	LL group	*P*	ES
Time to peak power (s)				
+25%	0.792 ± 0.097	0.870 ± 0.225	0.25	-0.46
+50%	0.845 ± 0.165	0.973 ± 0.188	0.06	-0.69
+75%	0.940 ± 0.216	1.046 ± 0.144	0.13	-0.57
+100%	1.053 ± 0.217	1.174 ± 0.244	0.17	-0.53
Time to peak velocity (s)				
+25%	0.901 ± 0.100	0.984 ±0.229	0.23	-0.47
+50%	0.943 ± 0.166	1.073 ±0.192	0.06	-0.69
+75%	1.025 ± 0.214	1.136 ±0.150	0.12	-0.58
+100%	1.137 ± 0.217	1.261 ± 0.248	0.17	-0.53
Time to peak force (s)				
+25%	0.661 ± 0.138	0.728 ± 0.216	0.34	-0.37
+50%	0.718 ± 0.209	0.898 ± 0.169	0.02*	-0.86
+75%	0.890 ± 0.346	1.037 ± 0.200	0.17	-0.52
+100%	1.071 ± 0.325	1.283 ± 0.405	0.13	-0.58

*Significance at ≤ 0.05. HL: Higher-level group; LL: Lower-level group; ES: Effect size.

Table 4. A comparison of matching pairs of significant correlations across two series of analyses. Series 1: All non-jump squat performance measures alongside all jump squat variables at +25% of body mass. Series 2: All non-jump squat performance measures alongside all jump squat variables at +100% of body mass.

	Variables	**r**	**z**	***P***
Series 1	Peak power +25% and peak velocity +25%	HL: r = 0.639 LL: r = 0.994	-5.14	< 0.0001
	Net impulse +25% and peak power +25%	HL: r = 0.698 LL: r = 0.961	-2.62	0.009
Series 2	time to peak power +100% and average RPD +100%	HL: r = -0.688 LL: r = -0.945	2.25	0.02
	time to peak velocity +100% and average RPD +100%	HL: r = -0.686 LL: r = -0.945	2.26	0.02

HL: Higher-level group; LL: Lower-level group; r = Pearson's correlation; z = Fisher's z; *P* = significance value for z.