Influence of Reactive Strength Index Modified on Force- and Power-Time Curves

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Influence of Reactive Strength Index Modified on Force- and Power-Time Curves

Submission Type – Original Investigation

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Abstract

Purpose: The reactive strength index modified (RSImod) has been recently identified and validated as a method of monitoring countermovement jump (CMJ) performance. The kinetic and kinematic mechanisms that optimize a higher RSImod score are, however, currently unknown. The purpose of this study, therefore, was to compare entire CMJ force-, power-, velocity- and displacement-time curves (termed temporal phase analysis) of athletes who achieve high versus low RSImod scores.

Methods: Fifty-three professional male rugby league players performed three maximal effort CMJs on a force platform and variables of interest were calculated via forward dynamics. RSImod values of the top (high RSImod group) and bottom (low RSImod group) twenty athletes' kinetic and kinematic-time curves were compared.

Results: The high RSImod group (0.53±0.05 vs. 0.36±0.03) jumped higher (37.7±3.9 vs. 31.8±3.2 cm) with a shorter time to take-off (TTT) (0.707±0.043 vs. 0.881±0.122 s). This was achieved by a more rapid unweighting phase followed by greater eccentric and concentric force, velocity and power for large portions (including peak values) of the jump, but a similar countermovement displacement. The attainment of a high RSImod score therefore required a taller, but thinner, active impulse.

Conclusions: Athletes who perform the CMJ with a high RSImod, as achieved by high jumps with a short TTT, demonstrate superior force, power, velocity and impulse during both the eccentric and concentric phases of the jump. Practitioners who include the RSImod calculation within their testing batteries may assume that greater RSImod values are attributed to an increase in these underpinning kinetic and kinematic parameters.

Keywords: Countermovement Jump, Temporal Phase Analysis, Velocity-Time, Displacement-Time, Stretch-Shortening Cycle, Rugby League

Introduction

The reactive strength index (RSI) accounts for the duration of force production to achieve a given jump height by dividing jump height by ground contact time.[1] RSI is a more easily attainable metric than force platform-derived variables and it provides greater insight into neuromuscular and stretch-shortening cycle (SSC) function than jump height alone.[2] The limitation of the RSI metric, however, is that it can only be calculated during jumping tasks which have an identifiable ground contact time (e.g. depth jumps etc.).[3] Many jumping tasks performed in sport, training programs and assessments are initiated with a countermovement while the feet are already in contact with the ground, ~~which may~~thus making~~e~~ the traditional calculation of RSI in these tasks redundant. Consequently, Ebben and Petushek[3] provided an alternative option to RSI, the RSI modified (RSImod), that can be applied to countermovement-initiated jumping tasks (e.g. countermovement jump (CMJ)), which replaces ground contact time with time to take-off (TTT) (calculated from the onset of the countermovement). The RSImod, which has mainly been calculated during the unloaded CMJ,[4, 5] is very reliable (intraclass correlation coefficient (ICC) of ≥ 0.85) [3-7] and is associated with force[4, 7] and velocity factors,[7] thus supporting its use as a measure of reactive strength.[7] Additionally, RSImod distinguishes between different jumping tasks,[3] sports,[5, 6] sexes[4, 8], and ~~age~~performance level,[9] thus demonstrating its usefulness as a vertical jump performance metric.

Although RSImod was shown to be related to force and power characteristics of the unloaded CMJ, such as rate of force development (RFD) (r = 0.56-0.66), peak force (r = 0.37-0.50) and peak power (r = 0.47-0.69),[4] ~~and loaded positively onto both force (peak force and RFD) and velocity (peak power and time to peak force and take-off) factors following a recently conducted factor analysis, both of these~~this study~~ies~~ only included 'gross' measures of CMJ performance (~~e.g.~~i.e. peak~~/mean~~ values) in ~~their respective~~its analyses. Gross CMJ performance measures (peak force, RFD, time to peak force and TTT) alone were also included in a recently conducted factor analysis, which placed these multiple gross measures into two main factors, force and speed, with RSImod found to load positively onto each of them (i.e. a greater RSImod was characterized by a high force and fast jump profile).[7] Whilst such gross measures may provide useful information pertaining to a specific portion of CMJ force- and power-time curves in relation to RSImod, they do not lend insight into how these curves change throughout the entire CMJ (i.e. unweighting, eccentric and concentric phases) in relation to RSImod. The latter approach is termed temporal phase analysis (TPA)[10, 11] and it was recently used to identify differences along entire CMJ force- and power-time curves between groups of athletes[8, 9, 12] and following different training programs.[13-16] The shape of the force-time curve influences the shapes of the resultant velocity- and displacement-time curves, which can also be included in a TPA,[8-10, 15] thus providing a~~n even~~ more comprehensive analysis of CMJ performance.

Only two of the aforementioned studies calculated RSImod while conducting a TPA of CMJ performance,[8, 9] with both studies reporting greater power and velocity, but not force, during the concentric phase of the jump for the group that attained a greater RSImod. The higher RSImod groups in both studies achieved greater RSImod values due to increased jump height alone, as TTT was similar between groups.[8, 9] The higher RSImod groups in both studies also adopted a jump strategy that was characterized by greater center of mass (COM) displacement during the eccentric and concentric phases of the jump, which has been previously shown to lead to greater jump height by increasing impulse via increased movement duration, although this ~~but reduce the~~is associated with reduced ground reaction forces.[17, 18] In both studies, therefore, the higher RSImod groups may not be considered to have demonstrated greater 'reactive' abilities during the CMJ than the lower RSImod groups, with the former groups seemingly placing more emphasis on maximizing jump height by virtue of increased countermovement displacements which increased TTT.[17, 18] Although not statistically significant, mean RSImod values were found to be greater for soccer vs. baseball athletes, despite the baseball athletes jumping higher due to their significantly longer TTT.[5] The latter example illustrates that CMJ height and RSImod are distinct variables. With the above in mind, the mechanisms that underpin a higher RSImod by achieving a higher jump and a shorter TTT are currently unknown. It is expected that this would demand a taller, but thinner, active impulse,[8] however this has not been quantified. Analysis of force-, power-, velocity- and displacement-time curves would enable the identification of the kinematic and kinetic profile required to achieve this desirable RSImod.

Conducting a TPA of CMJ performance in relation to athletes who attain high versus low RSImod values would highlight the expected underpinning kinetic and kinematic CMJ profile associated with achieving a greater RSImod score. Such results would be very useful for practitioners who include the RSImod calculation within their ongoing athlete monitoring battery but not through force platform analysis (i.e. those who calculate RSImod via wearable technology). The primary purpose of this study was, therefore, to quantitatively describe the influence of RSImod on CMJ force-, power-, velocity- and displacement-time curves by comparing these curves, using the TPA approach, between athletes who achieved differing (i.e. high versus low) RSImod values during the unloaded CMJ. A secondary purpose of this study was to explore relationships between RSImod and typically reported gross CMJ performance measures (peak and mean concentric force, power and velocity, and impulse) to validate previous findings.[4, 7] It was hypothesized that a high RSImod would be associated with larger force, power and velocity, but similar or smaller countermovement displacements, both in terms of the peak values attained and throughout large portions of the eccentric and concentric phases of the CMJ.

Methods

Subjects and Design

Fifty-three male professional rugby league players, comprised of an equal mix of forwards and backs, were recruited from English Super League (*n* = 22) and Championship (*n* = 31) clubs to participate in this study. Each subject attended a single testing session (cross-sectional study design) in a laboratory setting at ~~approximately~~ the same time of day during the first week of pre-season training. Written informed consent was provided prior to testing and the study was pre-approved by the institutional ethics committee. Subjects were ranked based on RSImod scores and then split into high (top 20 subjects) and low (bottom 20 subjects) RSImod groups post-testing. Dividing the subjects in this manner resulted in the high and low RSImod groups' mean RSImod scores being equal to one standard deviation above and below, respectively, the mean RSImod score attained by all subjects tested (*n* = 53). The physical characteristics of all subjects and those placed in each group can be seen in Table 1.

INSERT TABLE 1 ABOUT HERE

Methodology

Following a brief warm-up consisting of dynamic stretching and sub-maximal jumping, subjects performed three CMJs (interspersed with one minute of rest) to a self-selected depth. Subjects were instructed to perform the CMJ as fast and as high as possible, whilst keeping their arms akimbo. Any CMJs that were inadvertently performed with the inclusion of arm swing or leg tucking during the flight phase were omitted and additional CMJs were performed after a one minute of rest.

All CMJs were recorded at 1000 Hz using a Kistler type 9286AA force platform and Bioware 5.11 software (Kistler Instruments Inc., Amherst, NY, USA). Subjects were instructed to stand still for the initial one second of data collection[19, 20] to enable the subsequent determination of body weight (vertical force averaged over 1 s). Raw vertical force-time data were subsequently exported as text files and analyzed using a customized Microsoft Excel spreadsheet (version 2016, Microsoft Corp., Redmond, WA, USA).

The COM velocity was determined by dividing vertical force data (minus body weight) by body mass and then integrating the product using the trapezoid rule. Instantaneous power was calculated by multiplying vertical force and velocity data at each time point and COM displacement was determined by twice integrating vertical force data.[20] The start of the CMJ was identified in line with current recommendations.[19] The eccentric phase of the CMJ was defined as occurring between the instants of peak negative COM velocity and zero COM velocity. The concentric phase of the CMJ was deemed to have started when COM velocity exceeded 0.01 $m\cdot s^{-1}$ and finished at take-off.[8, 9] Take-off was identified when vertical force fell below five times the standard deviation of the flight phase force.[8, 9, 20] Eccentric and concentric mean and peak force, power, velocity and displacement were defined as the maximum and mean values attained during the eccentric and concentric phases, respectively. Net impulse was calculated during both the eccentric and concentric phases as the area under the net force-time curve (minus body weight) using the trapezoid rule.[17] All kinetic data were normalized by dividing them by body mass to enable between group comparison. Jump height was derived from vertical velocity at take-off.[20] RSImod was calculated as jump height divided by TTT (i.e. the time between the onset of movement and take-off).[3]

The TPA of the three CMJ trials was conducted by modifying individual force-, velocity-, power- and displacement-time curves from the onset of movement to the instant of take-off so that they each equaled 500 samples.[8-10] This was achieved by changing the time delta between the original samples (e.g. original number of samples/500) and subsequently re-sampling the data.[8-10] This resulted in an average sample frequency of 709 ± 44 Hz and 578 ± 81 Hz for the high and low RSImod groups' data, respectively, and allowed the averaged curve of each variable to be expressed over a percentage of normalized time (e.g. 0-100% of TTT).

Statistical Analyse~~i~~s

For each gross measure and the TPA, the mean output of the three CMJ trials was taken forward for statistical analysis. All pooled data ($n = 53$) satisfied parametric assumptions, but RSImod, peak force (eccentric and concentric) and peak eccentric power for the high RSImod group failed parametric assumptions. Mean differences in each parametric variable derived for high and low RSImod groups were, therefore, compared using independent t-tests whereas non-parametric variables were compared between groups via the Mann-Whitney U test. A two-way random-effects model ~~intraclass correlation coefficient (~~ICC~~)~~ was used to determine the relative between-trial reliability of each variable~~. The ICC values were~~ and interpreted according to previous work[21] where a value of ≥ 0.80 is considered highly reliable. Relationships between RSImod and both peak and mean concentric force, power and velocity, in addition to eccentric and concentric impulse, for the pooled data were explored using the Pearson correlation coefficient. Correlation coefficients were interpreted as trivial (0.0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9), and nearly perfect (0.9-1.0).[22] Independent t-tests, the Mann-Whitney U test, relationships and ICCs were performed using SPSS software (version 20; SPSS Inc., Chicago, IL, USA) with the alpha level set at $P \leq 0.05$. Absolute between-trial variability of each gross variable was calculated using the coefficient of variation (calculated in this study as the standard deviation divided by the mean) expressed as a percentage (%CV). A CV of ≤ 10% was considered to be reflective of acceptable variability in line with previous recommendations.[23] Effect sizes (Cohen's *d*) were calculated to provide a measure of the magnitude of the differences in each variable noted between groups and they were interpreted in line with previous recommendations which defined values of < 0.35, 0.35-0.80, 0.80-1.5 and > 1.5 as trivial, small, moderate, and large, respectively.[24] Likely group differences in force-, velocity-, power- and displacement-time curves were determined by plotting the time normalized average curves for each group along with the corresponding upper and lower 95% confidence intervals to create upper and lower control limits and identifying non-overlapping areas.[8, 25]

Results

All variables demonstrated high reliability and acceptable variability (Table 2). The mean RSImod for the entire subject group ($n = 53$) was 0.44 ± 0.09, and was achieved by a mean jump height of 0.35 ± 0.04 m and a mean TTT of 0.792 ± 0.115 s. RSImod was, as expected, larger for the high RSImod group, and was achieved by jumping higher with a shorter TTT due to shorter eccentric and concentric phase times (Table 2). Except for eccentric and concentric COM displacement which showed small differences only between groups (albeit, concentric COM displacement was significantly larger for the low RSImod group), all other kinetic and kinematic variables were significantly greater for the high RSImod group at the moderate to large level (Table 2).

INSERT TABLE 2 ABOUT HERE

Figure 1 shows how the different phases of the CMJ were defined for each group and how much time (as a percentage of total TTT) they each comprised. ~~Figure 2 illustrates that the high RSImod group produced more force, power and velocity within a shorter TTT than the low RSImod group.~~ The results of the TPA revealed that force was lower between 19% and 42% (during the unweighting phase) and greater between 61% and 86% (end of the eccentric phase through to just after peak concentric force), power was lower between 52% (mid-portion of the eccentric phase) and 60% and greater between 75% and 92% (most of the concentric phase), and velocity was lower between 43% and 57% (early part of the eccentric phase) and greater between 78% and 100% (most of the concentric phase and take-off) of the normalized TTT for the high RSImod group (Figures 2~~3~~ and 3~~4~~). Conversely, displacement was not different between groups at any time point during the~~of the~~ CMJ (Figure 3~~4~~).

INSERT FIGURE 1 ABOUT HERE

~~**INSERT FIGURE 2 ABOUT HERE**~~

INSERT FIGURE 2~~3~~ ABOUT HERE

INSERT FIGURE 3~~4~~ ABOUT HERE

RSImod demonstrated very large positive relationships with peak and mean concentric force and power and large-very large relationships with peak and mean concentric velocity (Figure 4~~5~~). There were also large positive relationships between RSImod and both eccentric and concentric impulse (Figure 5~~6~~).

INSERT FIGURE 4~~5~~ ABOUT HERE

INSERT FIGURE 5~~6~~ ABOUT HERE

Discussion

To the authors' knowledge, this is the first study to conduct a TPA of subjects who perform the CMJ with a high versus a low RSImod score. The main findings of this study are that subjects who performed the CMJ with a high RSImod, as achieved by jumping higher but with a shorter TTT (Table 2), demonstrated greater force, power and velocity in both the eccentric and concentric phases of the jump (Figures 2~~3~~ and 3~~4~~). These findings at the group comparison level were echoed by the correlational analyses conducted with all subjects' data pooled together, which yielded large-very large relationships between RSImod and peak and mean concentric force, power and velocity (Figure 4~~5~~). The high RSImod group also demonstrated similar eccentric COM displacement but less concentric COM displacement than the low RSImod group (Table 2). Based on these results, the original hypothesis of the study was accepted.

The results of this study are similar to those that previously reported gross measures of CMJ performance, in terms of RSImod being related to both force and velocity factors,[4, 7] thus reflecting a more impulsive CMJ strategy (Figure 5~~6~~). The fact that RSImod was correlated more highly with force than velocity is similar to the findings of Kipp et al.[7] whose recent factor analysis revealed that RSImod was more force, rather than velocity, dominant. The relationships between RSImod and peak concentric force and power are larger than the moderate correlation coefficients reported for the male collegiate athletes' data by Suchomel et al.[4], but agreed with peak concentric power (r = 0.47) showing a larger association with RSImod than peak concentric force (r = 0.37). The male collegiate athletes tested by Suchomel et al.[4] achieved a lower mean (across sports) RSImod of 0.41 ± 0.09, but a similar jump height, 0.35 ± 0.06 m, to the professional athletes tested in the present study, suggesting that the former demonstrated a longer TTT which would have likely reduced the peak forces attained in comparison to the present cohort,[17] leading to less impulsive jump. The mean RSImod for the whole group of subjects tested in this study was virtually identical to that of collegiate soccer players, who achieved the highest RSImod values of a range of athletes tested in an earlier study,[5] which highlights the high jump ability of the subjects tested. Additionally, the mean RSImod value achieved by the high RSImod group in the present study was much higher than any value that has been previously published, to the authors' knowledge, which may reflect a greater strength capacity[26] than the largely collegiate-level athletes tested in previous work.[4-6]

Only two studies have conducted a TPA of CMJ performance in addition to reporting RSImod values.[8, 9] The first study, which included a comparison of CMJ performance between professional senior and academy rugby league players, found that the senior players achieved greater RSImod scores along with greater power during a small portion of the concentric phase (just after the attainment of peak power) and greater velocity during the latter half of concentric phase of the jump.[9] The second study, which involved a sex comparison of CMJ performance, revealed that male athletes produced greater RSImod values than female athletes, along with greater concentric power immediately before, during and immediately after peak power, and greater velocity in the early eccentric phase and latter half of the concentric phase.[8] The latter study also found that male athletes demonstrated a lower COM position from just before the end of the eccentric phase and throughout ~~to approximately~~ the first half of the concentric phase of the jump.[8] The present results differed to these two earlier studies in that the high RSImod group demonstrated greater force, power and velocity (expressed as greater negative values of eccentric power and velocity in Figures 2~~3~~ and 3~~4~~) than the low RSImod group, but similar COM displacement throughout the jump. The main reason for the aforementioned differences in results between studies is likely due to the magnitude of the difference (in terms of the effect size) in RSImod values between groups being ~7 times greater in the present study than in the previously conducted work.[8, 9] The high RSImod group tested in the present study jumped higher and with a shorter TTT whereas both the senior rugby league players[9] and male athletes[8] tested previously only jumped higher than their opposing groups, which explains the much larger group differences in RSImod reported here.

The results of the TPA conducted in the present study illustrate that the high RSImod group performed the unweighting phase at a higher velocity, which then required a greater force to decelerate body mass during the eccentric phase; this combined effect led to greater eccentric power (Figures ~~3~~2 and 3~~4~~). This strategy seemingly did not 'overload' the athletes during the transition to, and during, the concentric phase, as force, velocity and power values were greater during a large portion of this phase of the jump (Figures 2~~3~~ and 3~~4~~). These findings suggest that the high RSImod group demonstrated superior ~~stretch-shortening cycle~~SSC function during the CMJ~~.~~,[6] by virtue of greater eccentric force and velocity likely increasing muscle spindle stimulation and elastic energy storage thus augmenting concentric force, velocity and power. The high RSImod group also jumped higher due to a greater force application (which would increase the acceleration of a given mass) rather than an increased ~~COM~~ countermovement displacement ~~(i.e. squat depth)~~, resulting in a net impulse generation that was characterized by a larger force and shorter TTT (Figure 1). This style of net impulse generation is beneficial to athletes whose success in many athletics tasks requires large forces to be produced in a time constrained manner.[27, 28] It is worth noting, however, that although the high RSImod group demonstrated the aforementioned jump strategy, this was likely due to this cohort being stronger than the low RSImod group, particularly during the eccentric phase of the jump as evidenced by superior force, velocity, power, and impulse during this phase. This supposition is based on recent work which showed both ~~the traditional~~ RSI ~~metric~~ (calculated following a series of drop jump tasks)[26] and RSImod[29] to be related to maximum lower body force capacity (as calculated during the isometric mid-thigh pull task) and higher for stronger athletes.[26] Additionally, although early correlational work suggested that a greater pattern of force application during the CMJ was more likely to increase jump height than increased strength,[30] several strength- and power-based intervention studies conducted by Cormie et al.[14-16]~~[13-16]~~ led to the desirable CMJ force, velocity and power profiles shown by the high RSImod group of the present study. It is suggested, therefore, that the jump strategy employed by the high RSImod group described in this study should be achieved through long-term strength and power training (similar to that described in earlier work[13-16]) rather than by acutely increasing one's RSImod score through technique modulation.

Practical applications

The results of the TPA suggest that athletes who perform the CMJ with a high RSImod, as achieved by high jumps and a short TTT, demonstrate superior force, power, velocity, and impulse during both the eccentric and concentric phases. Practitioners who include the RSImod calculation within their ongoing athlete monitoring battery may assume, therefore, that the attainment of a higher RSImod, either in comparison to other athletes or when comparing within-athlete pre-/post-testing scores, is attributed to an increase in these underpinning kinetic and kinematic parameters.

Conclusions

The present results support previous findings,[4, 6, 7] that RSImod provides a valid measure of impulsive CMJ performance, as evidenced through the results of both the TPA and correlational analyses presented here. Specifically, the greater eccentric and concentric force, power and velocity associated with attaining a high RSImod in the CMJ suggests superior utilization of ~~stretch-shortening cycle~~SSC in this task. Performing the CMJ with a high RSImod also results in a desirable net impulse generation which is characterized by a high force generation within a short time-period. It is suggested, therefore, that practitioners should aim to improve their athletes' RSImod scores through long-term strength and power training in line with previous work.[13-16] It is also recommended that caution should be taken with regards to acutely increasing an athlete's RSImod score through technique modification due to the associated increase in ground reaction forces which may increase injury risk. Instead, we suggest a progressive approach to increasing RSImod should be adopted via strength and power development. Finally, the present results do not support RSImod being increased by virtue of greater jump height and longer TTT (with the former outweighing the latter), as this may reflect reduced force and power capacity. It is important, therefore, to deconstruct RSImod into its constituent parts, especially when monitoring RSImod without the use of a force platform (i.e. through wearable technology), to more effectively inform the likely underpinning biomechanical adaptations.

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Figure Captions

Figure 1 – An illustration of how the unweighting, eccentric and concentric phases of the CMJ were defined for high RSImod (top) and low RSImod (bottom) groups, including the percentage of total time to take-off that they each comprised, based on force (black lines) and velocity (grey lines) data.

~~Figure 2 – Countermovement jump force-time (black lines) and velocity-time (grey lines) curves (top) and power-time (black lines) and displacement-time (grey lines) curves (bottom) for the high (dashed lines) and low (solid lines) RSImod groups.~~

Figure 2~~3~~ – A comparison of the countermovement jump force-normalized time (top) and power-normalized time (bottom) curves between the high (grey line) and low (black line) RSImod groups along with shaded 95% confidence intervals.

Figure 3~~4~~ – A comparison of the countermovement jump velocity-normalized time (top) and displacement-normalized time (bottom) curves between the high (grey line) and low (black line) RSImod groups along with shaded 95% confidence intervals.

Figure 4~~5~~ – Relationships between RSImod and peak (dark grey squares) and mean (light grey circles) concentric force (top), power (middle) and velocity (bottom) for the entire cohort (*n* = 53).

Figure 5~~6~~ – Relationships between RSImod and eccentric (top) and concentric (bottom) impulse for the entire cohort (*n* = 53).

Tables

Table 1: Physical characteristics of all subjects and groups (data represents the mean (standard deviation)).

	All Subjects (*n* = 53)	High RSImod Group (*n* = 20)	Low RSImod Group (*n* = 20)
Age (yrs)	23.4 (3.6)	22.4 (3.3)	23.7 (3.6)
Height (m)	1.84 (0.06)	1.81 (0.06)	1.86 (0.06)
Body Mass (kg)	96.4 (9.3)	92.1 (7.5)	98.8 (9.2)

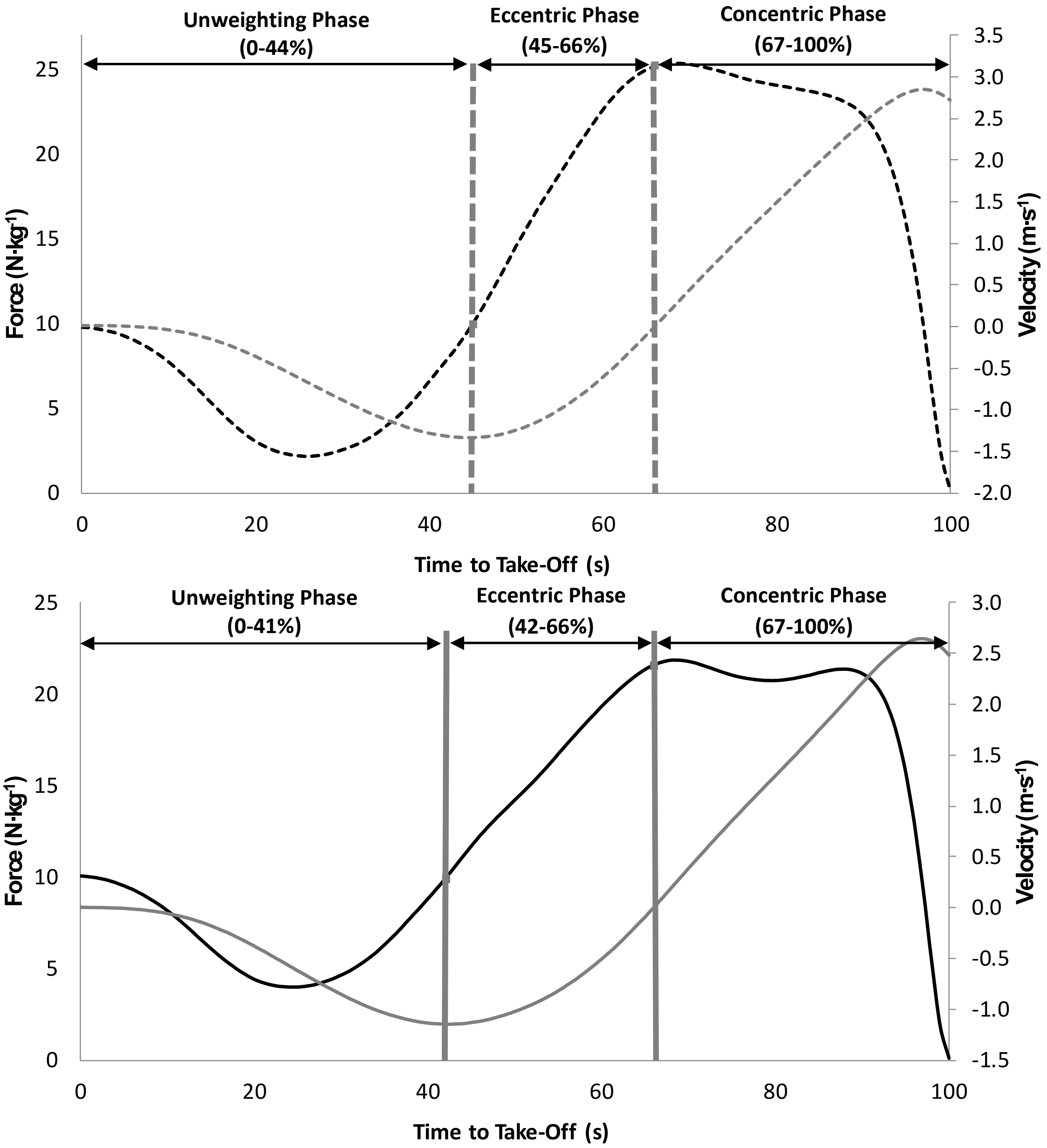
RSImod = Reactive Strength Index Modified

Table 2: Comparison of gross countermovement jump variables between high and low RSImod groups.

Jump Variables	High RSImod		Low RSImod		*P*	*d*	ICC	%CV
	Mean	**SD**	**Mean**	**SD**				
RSImod (ratio)	0.53	0.05	0.36	0.03	<0.001	4.12	0.89	5.7
Jump Height (cm)	37.7	3.9	31.8	3.2	<0.001	1.64	0.90	3.3
Time to Take-Off (s)	0.707	0.043	0.881	0.122	<0.001	1.90	0.88	4.2
Eccentric Phase Time (s)	0.153	0.018	0.202	0.041	<0.002	1.55	0.81	7.6
Concentric Phase Time (s)	0.239	0.020	0.292	0.035	<0.003	1.83	0.90	3.7
Eccentric COM Displacement (cm)	0.31	0.04	0.34	0.06	0.076	0.60	0.84	5.4
Concentric COM Displacement (cm)	0.41	0.05	0.45	0.06	0.020	0.74	0.89	3.7
Peak Eccentric Force ($N \cdot kg^{-1}$)	25.55	2.39	21.69	2.19	<0.001	1.69	0.88	3.9
Peak Concentric Force ($N \cdot kg^{-1}$)	26.16	2.08	22.66	1.87	<0.001	1.77	0.89	3.0
Peak Eccentric Power ($W \cdot kg^{-1}$)	20.59	5.07	14.58	3.63	<0.001	1.36	0.90	7.9
Peak Concentric Power ($W \cdot kg^{-1}$)	55.44	4.19	49.07	3.66	<0.001	1.62	0.91	2.4
Peak Eccentric Velocity ($m \cdot s^{-1}$)	1.37	0.18	1.14	0.19	<0.001	1.26	0.89	4.9
Peak Concentric Velocity ($m \cdot s^{-1}$)	2.85	0.15	2.66	0.13	<0.001	1.36	0.93	1.4
Eccentric Impulse (Ns·kg)	1.37	0.19	1.16	0.19	0.001	1.12	0.90	4.9
Concentric Impulse (Ns·kg)	2.72	0.15	2.55	0.15	<0.001	1.17	0.90	1.6

SD = Standard Deviation; ICC = Intraclass Correlation Coefficient; %CV = Percentage Coefficient of Variation; RSImod = Reactive Strength Index Modified; COM = Center of Mass

Figure 1


Unweighting Phase (0-44%)
Eccentric Phase (45-66%)
Concentric Phase (67-100%)
Force (N·kg-1)
Velocity (m·s-1)
0
5
10
15
20
25
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
20
40
60
80
100
Time to Take-Off (s)
Unweighting Phase (0-41%)
Eccentric Phase (42-66%)
Concentric Phase (67-100%)
Force (N·kg-1)
Velocity (m·s-1)
0
5
10
15
20
25
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
20
40
60
80
100
Time to Take-Off (s)

~~Figure 2~~

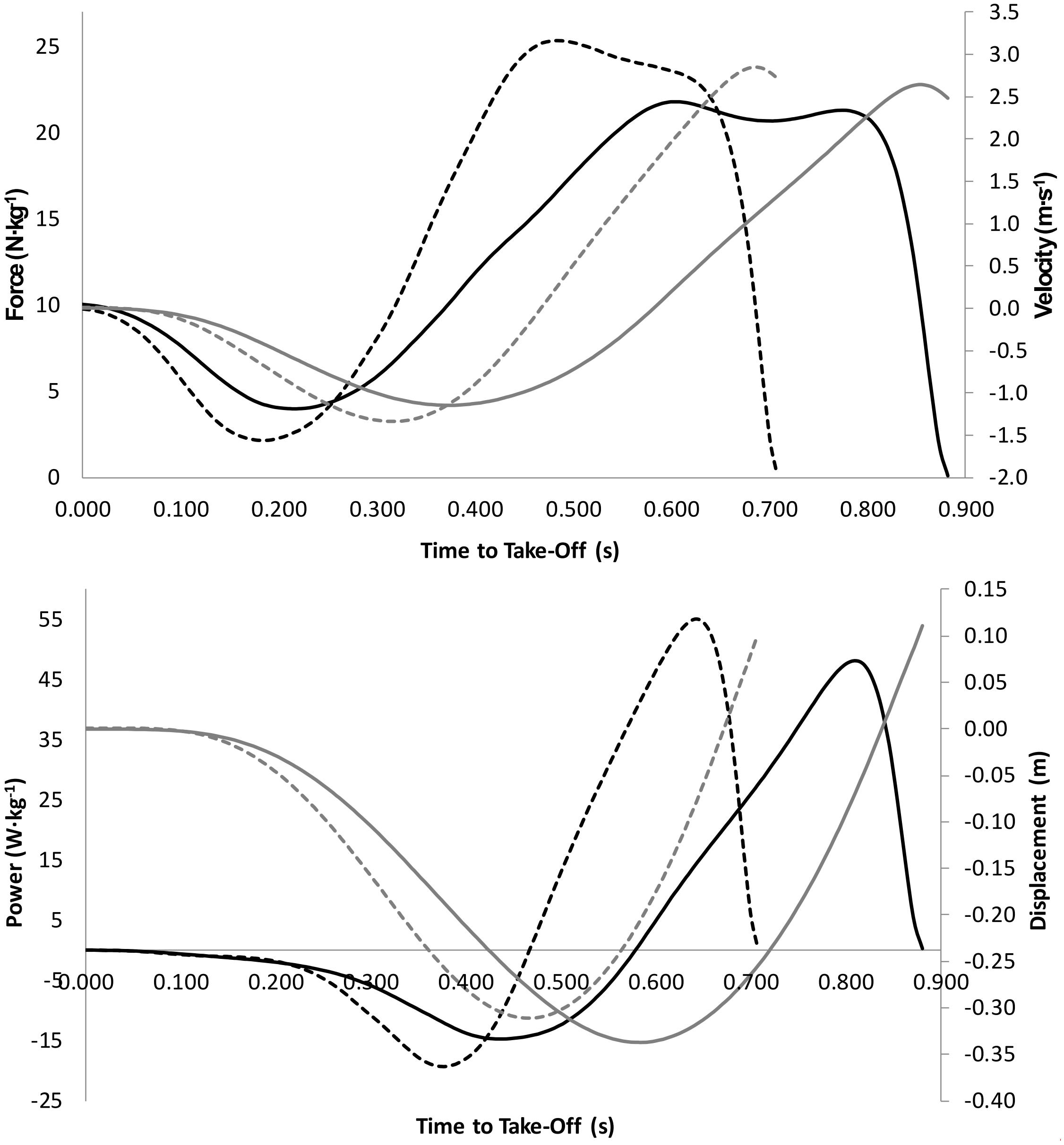

Force (N·kg^{-1})
25
20
15
10
5
0
Velocity (m·s^{-1})
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
Time to Take-Off (s)
Power (W·kg^{-1})
55
45
35
25
15
5
-5
-15
-25
Displacement (m)
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
Time to Take-Off (s)

Figure 2~~3~~

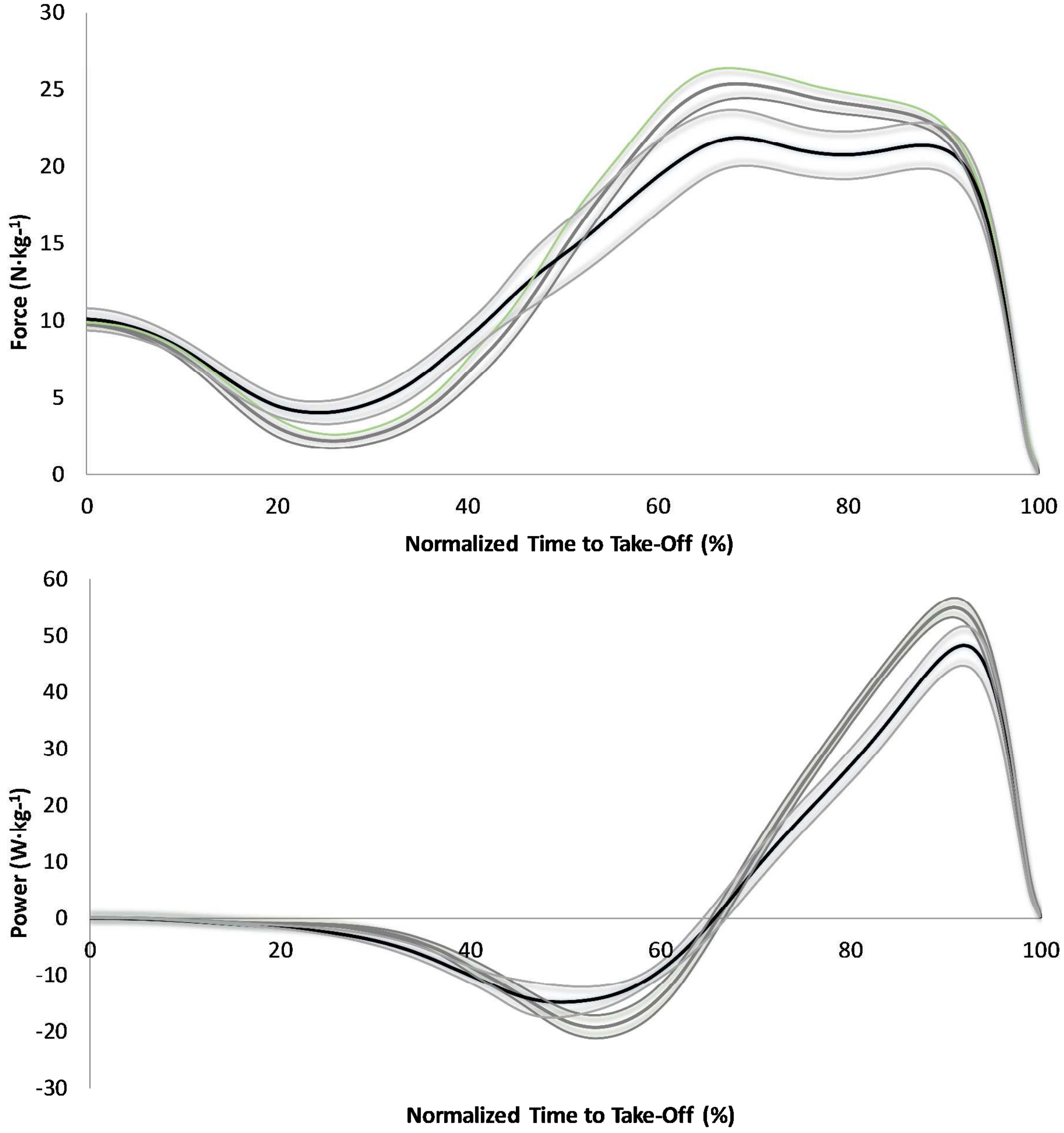

30
25
20
15
10
5
0
Force (N·kg-1)
0
20
40
60
80
100
Normalized Time to Take-Off (%)
60
50
40
30
20
10
0
-10
-20
-30
Power (W·kg-1)
0
20
40
60
80
100
Normalized Time to Take-Off (%)

Figure 3~~4~~

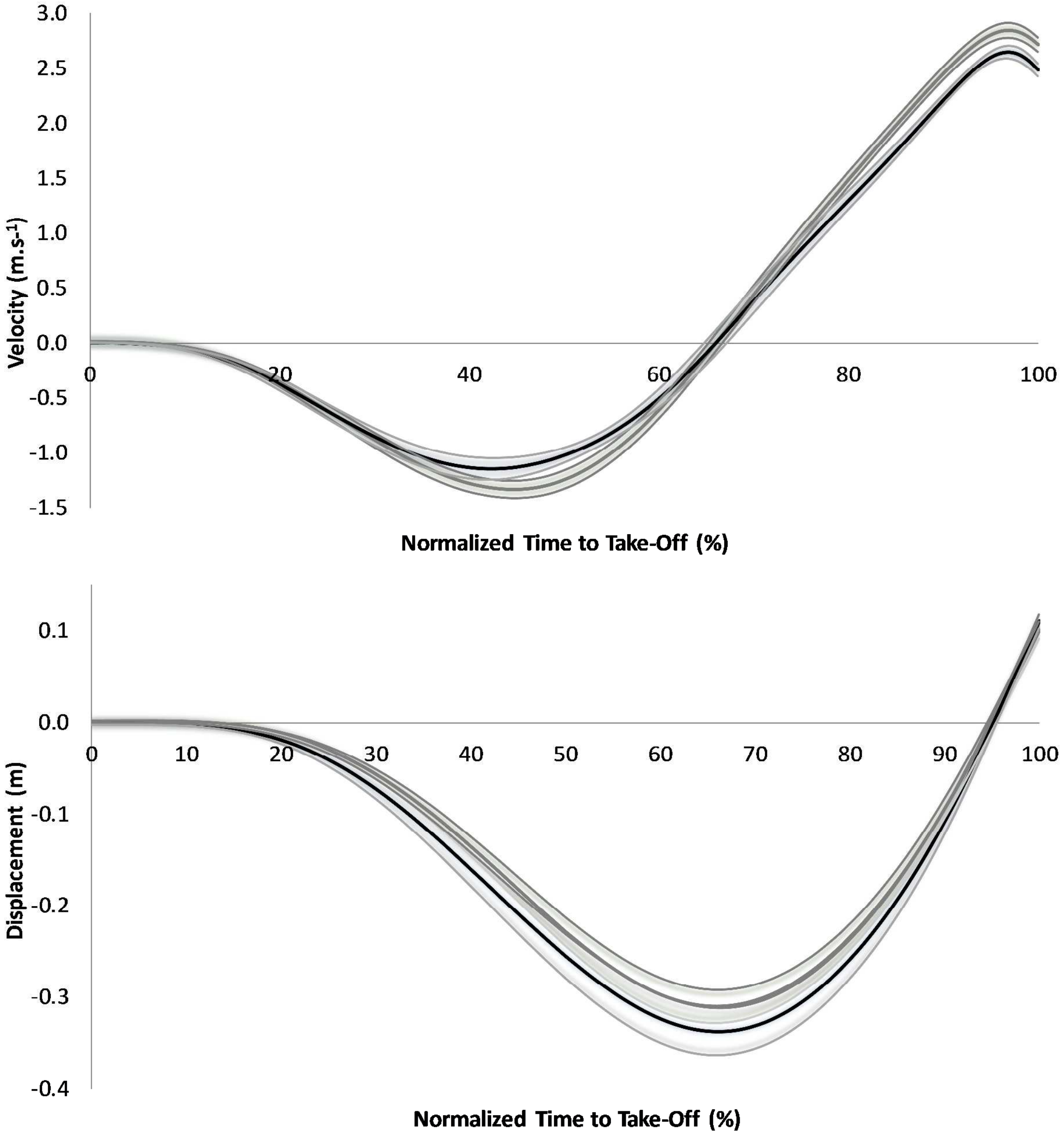

3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Velocity (m.s-1)
0
20
40
60
80
100
Normalized Time to Take-Off (%)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
Displacement (m)
0
10
20
30
40
50
60
70
80
90
100
Normalized Time to Take-Off (%)

Figure 4~~5~~

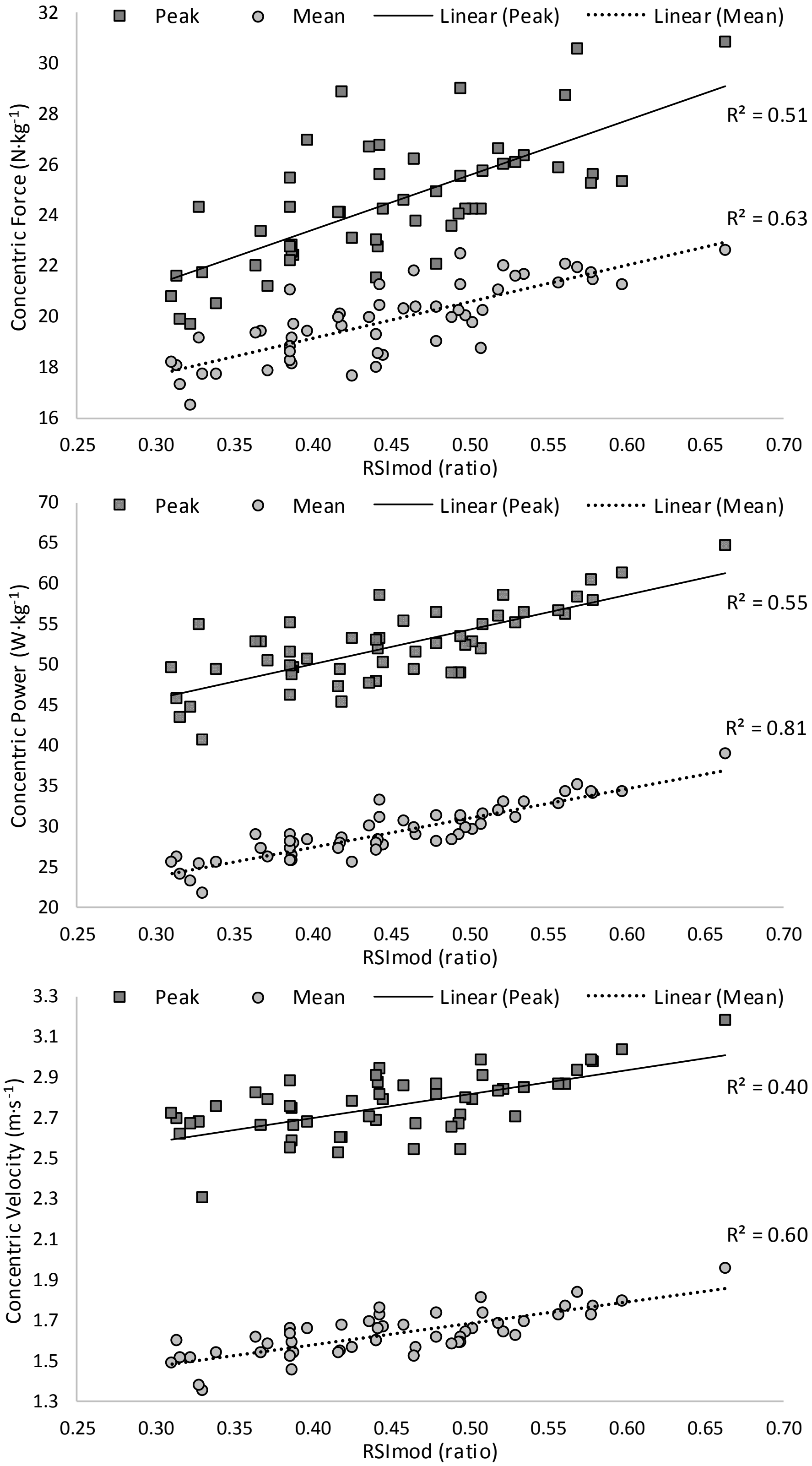
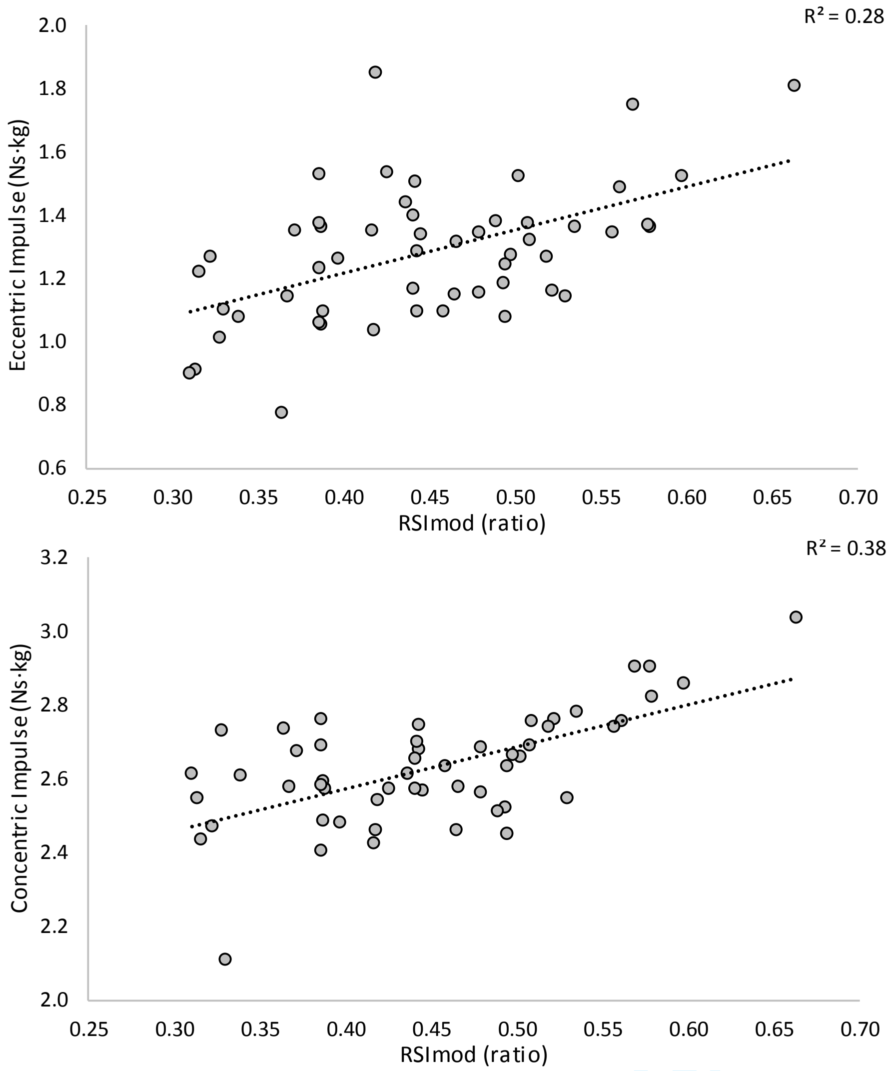

Peak
Mean
Linear (Peak)
Linear (Mean)
Concentric Force (N·kg⁻¹)
32
30
28
26
24
22
20
18
16
R² = 0.51
R² = 0.63
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
RSImod (ratio)
Peak
Mean
Linear (Peak)
Linear (Mean)
Concentric Power (W·kg⁻¹)
70
65
60
55
50
45
40
35
30
25
20
R² = 0.55
R² = 0.81
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
RSImod (ratio)
Peak
Mean
Linear (Peak)
Linear (Mean)
Concentric Velocity (m·s⁻¹)
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
1.3
R² = 0.40
R² = 0.60
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
RSImod (ratio)

Figure 5~~6~~


R² = 0.28
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
Eccentric Impulse (Ns·kg)
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
RSImod (ratio)
R² = 0.38
3.2
3.0
2.8
2.6
2.4
2.2
2.0
Concentric Impulse (Ns·kg)
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
RSImod (ratio)