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Phase-Specific Predictors of Countermovement Jump Performance That Distinguish Good From Poor Jumpers

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Abstract

Krzyszkowski, J, Chowning, LD, and Harry, JR. Phase-specific predictors of countermovement jump performance that distinguish good from poor jumpers. *J Strength Cond Res* XX(X): 000–000, 2020—The modified-reactive strength index (RSImod) is commonly examined during the countermovement vertical jump (CMJ) to assess neuromuscular characteristics (i.e., explosiveness, fatigue, adaptation, etc.) of an athlete. However, both phase-specific variables explaining RSImod and corresponding differences between good and poor jumpers are not well understood in trained populations. This study sought to (a) identify predictors of RSImod during the CMJ based on phase-specific temporal and rate of force development (RFD) variables, and (b) identify differences in those predictors between performers with high and low RSImod performances from a sample of collegiate male basketball players (n = 22; 20 ± 2 years; 1.99 ± 0.06 month; 93.8 ± 7.5 kg). Subjects performed 3 maximal effort CMJ trials while ground reaction force data was recorded using 2 force platforms. Phase-specific temporal and RFD variables were calculated and entered into separate stepwise regression models using backward elimination to identify predictors RSImod. Individuals were then categorized into high (n = 11; RSImod = 0.68 ± 0.10) and low (n = 11; RSImod = 0.48 ± 0.04) RSImod groups according to the overall median RSImod (RSImod = 0.55). Independent t-tests ($\alpha = 0.05$) were conducted and supplemented by Cohen's d effect sizes ($d \geq 1.2$, large) to compare groups relative to significant predictors identified by the linear regression models and related variables. The temporal regression model ($R^2 = 0.530$) retained unloading time and concentric time, whereas the RFD regression model ($R^2 = 0.429$) retained unloading RFD and braking RFD. The high RSImod group exhibited significantly greater RSImod scores ($d = 2.51$, $p < 0.001$) and jump heights ($d = 1.58$, $p < 0.001$), shorter times to takeoff ($d = 1.27$, $p = 0.007$) and concentric times ($d = 1.51$, $p = 0.002$), and a greater braking RFD ($d = 1.41$, $p = 0.005$) than the low RSImod group. Individuals targeting enhanced CMJ performance may consider exploring strategies or interventions to develop quicker unloading and concentric phases and increasing eccentric RFD abilities.

Key Words: explosiveness, force, jumping, rate of force development, speed, modified reactive strength index

Introduction

The countermovement vertical jump (CMJ) is an exercise commonly used to monitor an individual's neuromuscular ability (12). Countermovement vertical jump performance is typically defined by vertical jump height (JH) or its kinetic determinant, net relative impulse (23), which are gross performance measures that can also reflect an individual's physical readiness (4,31). Although JH provides gross performance and physical readiness information, it fails to characterize explosiveness because it does not account for temporal and rapid force production characteristics of the CMJ. Consequently, researchers and practitioners have started to expand CMJ analyses using additional performance variables to gain a more comprehensive insight of an athlete's explosive lower body qualities (25,28–30,32,36,38). One such variable is the modified reactive-strength index (RSImod), which is defined as the ratio between JH and the time to take-off (i.e., time from jump initiation to start of flight; time to takeoff [TTT]). Importantly, RSImod was shown to be a reliable and valid measure of explosive ability during jumping (9,22,40). Changes in RSImod can be achieved by altering JH, TTT, or both. This means that RSImod reflects both the force and time characteristics of the CMJ (22,27,40). A recent factor analysis explored the potential importance of force and time characteristics and revealed that RSImod was strongly associated with both "speed" and "force" factors (22), highlighting the importance of both qualities in determining RSImod performance.

Researchers largely recognize the value of RSImod relative to overall jumping ability, and have attempted to identify distinguishing features of more explosive jumpers. One study demonstrated that individuals with high RSImod values are characterized by greater JHs, shorter TTT, and greater peak force, peak power, and peak velocity production in both the "eccentric" (i.e., time between the instant of peak negative center of mass [COM] velocity and finished at the instant of zero COM velocity) and "concentric" (i.e., time between COM velocity becoming $>0\ \text{m}\cdot\text{s}^{-1}$ and take-off) phases of the CMJ compared with those with low RSImod scores (29). Another study comparing poor and good jumpers as defined by RSImod revealed that good jumpers displayed a significantly more rapid unloading time (i.e., time from CMJ initiation to the local minimum ground reaction force [GRF]) that preceded significantly greater propulsive impulse than poor jumpers (15). Even when CMJ performance is defined by JH, performance results are primarily determined by average "concentric" vertical

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force (CON-F) production preceded by greater average eccentric rate of force development (ECC-RFD), with the latter being the difference between the local minimum and maximum vertical GRF magnitudes divided by the time between them (24). Finally, changes in force- and power-time curves as a result of training have been shown to primarily occur in the "eccentric" phase of the CMJ (20). These results highlight the potential importance of quickness and rapid force production during the countermovement as they relate to explosive jumping performance, although the definitions for the phases in which variables were extracted is largely inconsistent.

Although the aforementioned studies revealed the general importance of temporal and force production variables during the countermovement relative to RSImod, inconsistent phase deconstruction methods in those studies make it difficult to truly understand the variables underlying changes in RSImod. The definitions for the "concentric" or "propulsion" CMJ phases are generally consistent among studies, whereas definitions for the phases within the countermovement are much less consistent (1,13,27). Commonly, the countermovement portion of the CMJ has been deconstructed into unweighing (the entire time when the GRF reading is below body weight, i.e., negative COM acceleration) and braking or "eccentric" (time of downward COM deceleration) phases according to the total body COM kinematics (3,15,19,30,32,38). However, a recent study suggested that the countermovement be deconstructed into unloading, eccentric yielding, and eccentric braking phases (Figure 1) to better reflect the COM movement effects, while also including the predominant muscle actions driving changes in COM movement where appropriate (13). For instance, the unloading phase defines the time when body weight is reduced and reaches the local minimum GRF magnitude, meaning it is quite different than the aforementioned unweighing phase. Although the eccentric braking phase is defined using a similar process to the braking phase mentioned previously, the eccentric yielding and eccentric braking phases are specified as eccentric phases, because they coincide with a negative sum of lower limb joint power (i.e., net eccentric muscle actions) and increasing and decreasing downward COM velocity, respectively. To date, the unloading, eccentric yielding, and eccentric braking phases have yet to be investigated with context to explaining changes in RSImod. Identifying temporal and force-time characteristics related to high RSImod values using these phases may provide detailed information about an athlete's explosive ability and translate more seamlessly to design and prescription of potential training interventions, because certain athletes may benefit more from targeting either temporal or force-production adaptations.

The current study had 2 purposes. The primary purpose was to identify predictors of RSImod using force-time variables within the unloading, eccentric yielding, eccentric braking, and concentric phases of the CMJ. Based on contemporary evidence described previously, we hypothesized that unloading time, eccentric braking time, and concentric time would be identified as the best temporal predictors of RSImod, whereas braking RFD would be identified as the best force-time predictor of RSImod. The secondary purpose of this study was to determine whether good jumpers, defined by RSImod scores, display superior performance in the identified force-time predictor variables. For this purpose, it was hypothesized that the high RSImod group would demonstrate a quicker unloading phase, quicker concentric phase, and a greater braking RFD during the CMJ.

Methods

Experimental Approach to the Problem

To identify the significant phase-specific temporal and force predictors of RSImod, multiple regression analyses were conducted to identify predictors of RSImod using (a) temporal and (b)

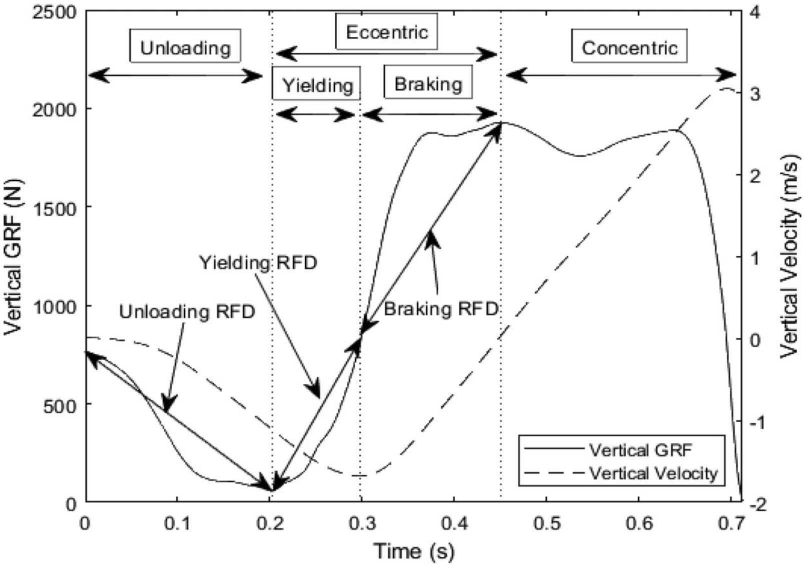

Figure 1. Example CMJ force- and velocity-time curves illustrating the CMJ phases. CMJ = countermovement jump; the left-most vertical axis represents the vertical GRF, and the right-most vertical axis represents the COM velocity. Unloading represents the unloading phase; eccentric represents the eccentric phase; yielding represents the eccentric yielding subphase of the overall eccentric phase; braking represents the eccentric braking subphase of the overall eccentric phase; and concentric represents the concentric phase. Rate of force development is also represented for the unloading, eccentric yielding, and eccentric braking phases. GRF = ground reaction force.

RFD variables. Subjects were also stratified into a high or low RSImod groups and compared with respect to the identified temporal and RFD predictors of RSImod. This study design was used in an attempt to illustrate important CMJ characteristics that distinguish poor and good jumpers with hopes of providing practitioners with qualities that may be inherent to a better jumping performance.

Subjects

Twenty-two collegiate male basketball athletes participated in this study (mean ± *SD* height: 1.99 ± 0.06 m; mass: 93.8 ± 7.5 kg; age: 20 ± 2 years [age range: 18 years and older]). Basketball players were examined because the demands of their sport require vertical jumps to be executed for maximum height, quickness, or both (39), making RSImod a valuable metric to understand for the population. Testing occurred before any team-related activities (i.e., strength & conditioning, practice, etc). Subjects were also free of any injury that would hamper their ability to participate in team-specific physical activities or complete the experimental protocol. Before testing, the subjects were informed about the details of the study, and provided written informed consent as approved by the Texas Tech University institutional review board.

Procedures

Subjects were required to attend one testing session. The height, age, and mass of the subjects was collected after the consent process. The subjects completed a ~10-minute warm-up that was led by the strength and conditioning staff. After the warm-up, subjects performed up to 5 CMJ familiarization trials on the force platforms. Subjects then completed 3 maximal effort CMJ trials with up to 2–minutes of rest between each trial. Subjects were instructed to perform the CMJ "as fast and as high as possible" using their preferred countermovement strategies (i.e., arm swing, depth, etc.) to maximize CMJ and RSImod performance (16). During the CMJ trials, kinetic data were recorded at 1,000 Hz using 2 three-dimensional force platforms (OPT464508, Advanced Mechanical Technology, Inc., Watertown, MA) interfaced to a PC running Nexus software (version 2.6; Vicon Motion Systems, Ltd., Oxford, United Kingdom).

Data Processing. Raw GRF data were processed in Matlab (r2019a; The MathWorks, Inc., Natick, MA). The GRF data were smoothed using a fourth-order, bi-directional (i.e., dual-pass), low pass Butterworth digital filter using a cutoff frequency of 50 Hz, with the order and cutoff before the 2 passes. Filtered vertical GRF data from the 2 force platforms were summed to create a total vertical GRF acting on the body COM. Vertical COM acceleration was calculated using Newton's law of acceleration ($a = \Sigma F \cdot mass^{-1}$), where mass was calculated by dividing body weight (i.e., the average vertical GRF during the first 500 data points of quiet standing before the start of the CMJ trial) by the absolute value of gravitational acceleration ($9.81\ m \cdot s^{-1}$). Vertical COM velocity was obtained by calculating the time-integral of vertical COM acceleration using the trapezoidal rule. Vertical COM position was then calculated as the time-integral of the vertical COM velocity, also using the trapezoidal rule.

The CMJ was deconstructed into the phases previously described (13) as illustrated in Figure 1. Specifically, the start of the CMJ (i.e., the start of the unloading phase), was defined as the instant when the vertical GRF decreased by more than 2.5% of the calculated body weight value (33). The end of the unloading phase and the start of the eccentric yielding phase was defined as the local minimum vertical GRF succeeding the start of the unloading phase. The end of the eccentric yielding phase and the beginning of the eccentric braking phase was identified as the instant of peak negative COM velocity. The end of the eccentric braking phase and the beginning of the concentric phase was identified as the instant when vertical COM velocity was greater than $0\ m \cdot s^{-1}$ after the start of eccentric braking. The end of the concentric phase was identified as the instant when the vertical GRF decreased below 20 N after the start of the concentric phase. The time durations of each phase were extracted in units of seconds. Center of mass depth was calculated as the change in vertical COM position from the start of the unloading phase to the end of the eccentric braking phase. Center of mass depth was included to supplement TTT and explain whether potential differences between low and high RSImod groups were influenced by depth. Rate of force development values for each phase were calculated as the change in the vertical GRF between the start of end of the phases divided by the time between the 2 GRF values. All RFD variables were normalized to body mass.

Table 1

Stepwise regression model summary for the temporal prediction model.*†

Model inputs	b	*SE* b	β	*t*	*p*	95% CI
Step 1						
Constant	1.355	0.153		8.857	<0.001	1.033 to 1.678
Unloading time	−0.683	0.173	−0.667	−3.947	<0.001	−1.048 to −0.318
Yielding time	−0.669	0.565	−0.205	−1.183	0.253	−1.861 to 0.524
Braking time	−0.898	0.757	−0.272	−1.186	0.252	−2.494 to 0.699
Concentric time	−1.443	0.629	−0.505	−2.296	0.035	−2.279 to −0.117
Step 2						
Constant	1.279	0.140		9.113	<0.001	0.984 to 1.574
Unloading time	−0.626	0.168	−0.611	−3.726	0.002	−0.979 to −0.273
Braking time	−1.216	0.715	−0.369	−1.701	0.106	−2.718 to 0.286
Concentric time	−1.343	0.630	−0.469	−2.132	0.047	−2.666 to −0.020
Step 3						
Constant	1.244	0.146		8.545	<0.001	0.939 to 1.549
Unloading time	−0.592	0.175	−0.578	−3.384	0.003	−0.959 to −0.226
Braking time	−2.063	0.489	−0.721	−4.221	<0.001	−3.086 to −1.040

*B = unstandardized coefficients; *SE* B = standardized coefficients *SE*; β = standardized coefficients; t = t value; 95% CI = 95% confidence intervals.

†Significance was set at $p < 0.05$.95% bias corrected and accelerated confidence intervals are reported. Confidence intervals and *SE*s based on 1,000 bootstrap samples.

Table 2

Stepwise regression model summary for the RFD prediction model.*†

Model inputs	b	*SE* B	β	*t*	*p*	95% CI
Step 1						
Constant	0.325	0.074		4.381	<0.001	0.169 to 0.481
Unloading RFD	−0.003	0.001	−0.442	−2.440	0.025	−0.005 to 0.000
Yielding RFD	0.001	0.001	0.132	0.704	0.490	−0.001 to 0.003
Braking RFD	0.002	0.067	0.489	2.613	0.018	0.000 to 0.003
Step 2						
Constant	0.346	0.067		5.154	<0.001	0.205 to 0.486
Unloading RFD	−0.003	0.001	−0.468	−2.671	0.015	−0.005 to −0.001
Braking RFD	0.002	0.001	0.530	3.027	0.007	0.001 to 0.003

*B = unstandardized coefficients; *SE* B = standardized coefficients *SE*; β = standardized coefficients; t = t value; 95% CI = 95% confidence intervals; RFD = rate of force development.

†Significance was set at $p < 0.05$.95% bias corrected and accelerated confidence intervals are reported. Confidence intervals and *SE*s based on 1,000 bootstrap samples.

Statistical Analyses

The average across the 3 trials was calculated for each variable per subject and used for statistical analyses conducted in SPSS software (version 25; IBM Corp, Armonk, NY). Stepwise multiple regressions using backward elimination were conducted for the (a) temporal (i.e., unloading time, yielding time, braking time, and concentric time) and (b) RFD variables (i.e., unloading RFD, yielding RFD, and braking RFD) to determine which variables significantly predicted RSImod. Although other regression methods exist such as least absolute shrinkage selection operator (LASSO) method, stepwise forward elimination method, and multiple linear regression method, the stepwise backward elimination method was chosen because of its use in prior research (6,8,10,11,17,44). Multicollinearity was assessed and all the variables entered into the regression model had to have had tolerance values greater than 0.20 and variance inflation factors less than 4.0. The significant predictor variables from the 2 regression models were then compared between the high and low RSImod groups using independent *t*-tests ($\alpha = 0.05$), with the high RSImod group defined by RSImod values greater than or equal to the median RSImod of the overall group (median = 0.55). Equality of variances was assessed using Levene's test. Cohen's *d* effect sizes (*d*), which were calculated to supplement the pairwise comparisons were interpreted based on Hopkin's (18) scale (0.0 < trivial ≤0.2 small <0.6 ≤moderate <1.2 <large ≤2.0 <very large). Finally, 95% confidence intervals (CIs) were calculated to provide the range containing the true means of this specific population (43).

Results

Results of the temporal and RFD regression analyses are provided in Tables 1,2, and 3. The multiple regression analysis indicated unloading time and concentric time to be the significant temporal predictors of RSImod (Table 3), explaining a combined 53.0% of the variance in RSImod scores. Yielding time and braking time were not significant temporal predictors of RSImod, and were removed from the regression model. Unloading RFD and braking RFD were retained as the significant RFD predictors of RSImod (Table 3), explaining a combined 42.9% of the variance in RSImod scores. Yielding RFD was not a significant RFD predictor of RSImod and was removed from the regression model.

Descriptive subject data for the overall sample and the high- and low-RSImod groups are provided in Table 4. There were no statistically significant differences detected between groups for age, height, or body mass (*d* values ≤0.58; *p* values >0.05; Table 4). As expected, subjects in the high RSImod group produced significantly greater RSImod values, which coincided with significantly greater JHs and braking RFD (*d* values ≥1.41; *p* values <0.05; Table 5). In addition, the high RSImod group also demonstrated a significantly quicker concentric phase and TTT when compared with the low RSImod group (*d* values ≥1.27; *p* values <0.05; (Tables 5).

Discussion

The main purpose of this investigation was to identify significant temporal and RFD predictors of RSImod. In support of our hypothesis, unloading time and concentric time were identified as significant temporal predictors, whereas unloading RFD and braking RFD were identified as significant RFD predictors. Yielding time and braking time were not retained as significant temporal predictors, whereas yielding RFD was not retained as a significant RFD predictor. General comparison of the explained variance in the temporal and RFD regression models suggests that

Table 3

Stepwise linear regression model summary for the RSImod prediction.*†

Regression equation	*R*	R^2	Adj.R^2	*SEE*	*p*
1a. RSImod = 1.355 − (0.683) UT − (0.669) YT − (0.898) BT − (1.443) CT	0.791	0.625	0.537	0.085	<0.001
1b. RSImod = 1.244 − (0.592) UT − (2.063) CT	0.728	0.530	0.480	0.090	<0.001
2a. RSImod = 0.325 − (0.003) uRFD + (0.001) yRFD + (0.002) bRFD	0.666	0.444	0.351	0.100	0.013
2b. RSImod = 0.346 − (0.003) uRFD + (0.002) bRFD	0.655	0.429	0.369	0.100	0.005

*RSImod = modified reactive strength index; UT = unloading time; YT = yielding time; BT = braking time; CT = concentric time; uRFD = unloading rate of force development; yRFD = yielding rate of force development; bRFD = braking rate of force development.

†Model 1a corresponds to the temporal prediction full model. Model 1b corresponds to the temporal prediction model following backward elimination. Model 2a corresponds to the RFD prediction full model. Model 2b corresponds to the RFD prediction model following backward elimination.

Table 4

Demographic characteristics (mean ± *SD*) for all subjects (*n* = 22), high RSImod group (*n* = 11), and low RSImod group (*n* = 11).*

Variable	All subjects	High RSImod	Low RSImod	*p*	*d*
Age (yrs)	20.2 ± 2.00	20.5 ± 2.21	20.0 ± 1.84	0.606	0.22
Height (m)	1.99 ± 0.06	1.97 ± 0.05	2.01 ± 0.07	0.205	0.56
Body Mass (kg)	93.8 ± 8.48	91.8 ± 4.25	95.8 ± 11.1	0.283	0.48

*Data are presented as mean ± *SD*; *d*, Cohen's *d* effect size.

temporal characteristics may explain more of the variance in RSImod than RFD characteristics. The secondary purpose of this study was to determine whether differences exist between high and low RSImod groups existed for the predictors retained by the 2 regression models. In support of our hypothesis, the high RSImod group was characterized by shorter concentric phase and TTT durations, as well as a greater braking RFD in comparison to low RSImod group. There were no statistical differences between high and low RSImod groups for COM depth, unloading time, and unloading RFD. The high RSImod group achieved the greater RSImod values by way of greater JHs and a shorter TTT than the low RSImod group. This finding was consistent with previous work demonstrating that high RSImod groups were characterized by greater JHs and shorter TTT (29,37,41).

Focusing on the temporal descriptors of RSImod is important because prior work demonstrated that higher RSImod scores were achieved when individuals focused on executing the CMJ quickly rather than at their self-selected speed (34). Our identification of unloading time and concentric time as significant temporal predictors of RSImod suggests that individuals should focus on initiating and completing the CMJ as quickly as possible, and that the temporal components of the yielding and braking phases may be less important in improving RSImod scores. Initiating and completing the CMJ as rapidly as possible may be an expected result because unloading (15) and concentric times (29) have been shown to distinguish good from poor jumpers when groups were separated according to RSImod. Rapid concentric durations are likely a secondary consequence of enhanced unloading or eccentric output (13), and our results illustrate the importance of initiating the CMJ with maximum volition, because it relates to maximizing RSImod. The initial movement strategy to begin the unloading phase has been described as a relaxation of the lower extremity muscles to allow the hip and knee joints to flex under the effects of gravity (26). However, experimental data from recent investigations showed that individuals may also initiate the CMJ by producing positive power (i.e., concentric muscle action) about the hip (14) or knee (21) joints. Speculatively, these active unloading strategies could be potential targets during training to increase quickness during the unloading phase.

Our identification of unloading RFD and braking RFD as significant predictors of RSImod may provide additional support for our speculation that active unloading strategies could be targeted abilities during the CMJ. These current unloading RFD results suggest that active unloading strategies performed using concentric muscle actions may present as an increase in "how much" unloading occurs in addition to how rapidly unloading is completed. This further supports our working hypothesis that active CMJ initiation strategies are important for explosive jumping performance while also revealing that such strategies may lead to more rapid force production during the eccentric braking phase. Still, research should be directed toward interventions that specifically target or examine active unloading strategies. From the perspective of rapid eccentric force production, previous work determined that eccentric RFD, with the eccentric phase defined similarly to the definition herein, was strongly correlated with RSImod (1) and JH (25). Thus, a greater braking RFD may be responsible for any differences in rapid eccentric force production (i.e., during the combined eccentric yielding + eccentric braking phases) between poor and good jumpers.

Shorter TTT results have been associated with smaller COM depths in adolescent athletes (35) that presumably coincided with a faster overall countermovement (i.e., faster unloading, yielding, and/or braking phases). It was also shown that, in recreationally active jumpers, high RSImod groups exhibited moderately faster TTT than low RSImod groups through significantly faster unloading times (15). However, the results of this study showed that the shorter TTT in the high versus low RSImod group comparison was achieved through faster concentric times and not faster unloading times nor via faster countermovements achieved through smaller COM depths. This suggests that maximizing jump performance via faster unloading may be unique to lesser-skilled or recreationally active samples because the typical jump performances in that study (15) were noticeably worse (median RSImod score = 0.46) than to the current sample of male collegiate basketball players, who showed no differences in unloading strategies. Consistent with our results, prior work demonstrated that high RSImod groups had shorter concentric phases than low RSImod groups in a sample of professional male rugby players (29). The quicker concentric phases achieved by the high RSImod group can be interpreted as greater concentric velocities achieved by the high RSImod group, which is consistent with previous comparisons

Table 5

Performance, temporal, and RFD parameters for the high and low RSImod groups.*†

	High RSImod		Low RSImod			
Variable	Mean ± *SD*	95% CI	Mean ± *SD*	95% CI	*p*	*d*
RSImod‡	0.68 ± 0.10	0.61 to 0.75	0.49 ± 0.04	0.46 to 0.52	<0.001	2.51
Jump height‡ (m)	0.49 ± 0.05	0.45 to 0.52	0.41 ± 0.04	0.39 to 0.44	<0.001	1.58
TTT‡ (s)	0.73 ± 0.10	0.66 to 0.80	0.86 ± 0.10	0.79 to 0.92	0.007	1.27
COM depth (m)	−0.25 ± 0.05	−0.29 to −0.22	−0.30 ± 0.04	−0.33 to −0.27	0.055	0.87
Unloading time (s)	0.23 ± 0.12	0.15 to 0.31	0.23 ± 0.13	0.14 to 0.32	0.933	0.04
Concentric time‡ (s)	0.23 ± 0.003	0.03 to 0.42	0.28 ± 0.04	0.25 to 0.31	0.002	1.51
Unloading RFD ($N\cdot kg^{-1}\cdot s^{-1}$)	−38.5 ± 18.7	−51.2 to −25.8	−34.1 ± 20.8	−48.3 to −20.0	0.607	0.22
Braking RFD‡ ($N\cdot kg^{-1}\cdot s^{-1}$)	93.0 ± 39.1	66.4 to 119.7	50.5 ± 17.2	38.8 to 62.2	0.005	1.41

*RSImod = modified reactive strength index; TTT = time to takeoff; COM depth = center of mass depth; unloading RFD = unloading rate of force development; braking RFD = braking rate of force development; *d* = Cohen's *d* effect size; RFD = rate of force development.

†Data are presented as mean ± *SD*, 95% confidence interval in brackets.

‡Statistically significant difference between groups ($\alpha = 0.05$).

between high and low RSImod scores (29). In previous comparisons of RSImod, the high RSImod groups demonstrated superior force production and achieved greater velocities during the eccentric phase (29,31), suggesting that the high RSImod groups produced greater RFD during the eccentric phase. In addition, previous work has shown that high eccentric RFD was significantly correlated with concentric vertical force and reflects a rapid stretching of the muscle-tendon system and results in a higher amount of force production during the propulsive (i.e., concentric phase; shortening portion of muscle-tendon system) phase of the jump (5,24). The difference in concentric time we observed between the high and low RSImod groups similarly seems to be a positive consequence of increased braking RFD and suggests that achieving quick concentric times is a high-level skill dependent in part on an efficient eccentric phase (2). Collectively, these results suggest that less skilled individuals may rely on unloading strategies to improve their jumping performance, whereas highly-trained athletes (e.g., professional male rugby players; male collegiate basketball players) may already possess sufficient unloading strategies and any differences in RSImod within such populations may center on the capacity for eccentric mechanical output.

A potential limitation of this study was the relatively small group sample sizes after dichotomizing individuals based on their RSImod values. However, strength & conditioning practitioners working with similar populations are unlikely to have larger sample sizes than this study. Nonetheless, effect sizes were used to address this limitation and provide readers with additional information to generate conclusions when interpreting the data (42). Another possible limitation of this study was the use of 3 trials for data analysis. However, previous relevant work has also used 3 trials (1,7,15), and we maximized the number trials we could collect given the time constraints of an NCAA Division 1 basketball program.

In summary, increased RSImod performance (i.e., greater explosiveness) in collegiate men's basketball players was best predicted from a temporal perspective by shorter unloading and concentric times. From a rapid force production perspective, increased explosiveness in this population was best predicted by increased unloading and braking RFDs. Strategies favoring shorter movement phases could be ideal for quick improvements in explosive abilities, because they would return a shorter TTT and result in a higher RSImod score even when JH remains constant. Strategies favoring greater unloading and braking RFDs seem important, although comparisons between high and low RSImod groups suggests that a greater braking RFD, a quicker concentric phase duration, or both should be initially targeted by poor jumpers.

Practical Applications

The current study revealed the importance of unloading time, concentric time, unloading RFD, and braking RFD in predicting RSImod performance. In our population of collegiate male basketball players, good jumpers were distinguished from poor jumpers based on quicker concentric phases and greater braking RFD abilities. This investigation demonstrated that prediction models can be used to reveal which qualities can be targeted to improve RSImod. Whereas a comparison of high and low RSImod groups can be used to show what *should be* initially targeted to improve RSImod in male collegiate basketball players.

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