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Relationship Between Strength Characteristics and Unweighted and Weighted Vertical Jump Height

Jenna M. Kraska, Michael W. Ramsey, G. Gregory Haff, Nate Fethke, William A. Sands, Margaret E. Stone, and Michael H. Stone

Purpose: To investigate the relationship between maximum strength and differences in jump height during weighted and unweighted (body weight) static (SJ) and countermovement jumps (CMJ). ***Methods:*** Sixty-three collegiate athletes (mean ± SD; age= 19.9 ± 1.3 y; body mass = 72.9 ± 19.6 kg; height = 172.8 ± 7.7 cm) performed two trials of the SJ and CMJ with 0 kg and 20 kg on a force plate; and two trials of mid-thigh isometric clean pulls in a custom rack over a force plate (1000-Hz sampling). Jump height (JH) was calculated from flight time. Force-time curve analyses determined the following: isometric peak force (IPF), isometric force (IF) at 50, 90, and 250 ms, and isometric rates of force development (IRFD). Absolute and allometric scaled forces, [absolute force/(body mass$^{0.67}$)], were used in correlations. ***Results:*** IPF, IRFD, $F50_a$, F50, F90, and F250 showed moderate/strong correlations with SJ and CMJ height percent decrease from 0 to 20 kg. IPF_a and $F250_a$ showed weak/moderate correlations with percent height decrease. Comparing strongest (n = 6) to weakest (n = 6): *t* tests revealed that stronger athletes (IPF_a) performed superior to weaker athletes. ***Conclusion:*** Data indicate the ability to produce higher peak and instantaneous forces and IRFD is related to JH and to smaller differences between weighted and unweighted jump heights. Stronger athletes jump higher and show smaller decrements in JH with load. A weighted jump may be a practical method of assessing relative strength levels.

Keywords: strength, strength deficit, and rate of force development

Strength is an attribute often associated with superior performance in sport.[1–4] Several of the characteristics associated with strength (eg, peak force, rate of force

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Kraska, Ramsey, Margaret E. Stone, and Michael H. Stone are with the Center of Excellence for Sport Science and Coach Education, Department of Kinesiology, Leisure, and Sports Science, East Tennessee State University, Johnson City, TN. Haff is with the Department of Human Performance and Applied Exercise Physiology, Division of Exercise Physiology, West Virginia University School of Medicine, Morgantown, WV. Fethke is with Occupational & Environmental Health, University of Iowa, Iowa City, IA. Sands is with the Monfort Family Human Performance Research Laboratory, Department of Kinesiology, Mesa State College, Grand Junction, CO.

development [RFD], velocity, and power-generating capacity) have been identified as underlying mechanisms related to sports performance, particularly in the vertical jump.[3,5–8,28] According to several authors, success in sport depends upon the development of strength as well as power, both of which contribute to vertical jump performance.[3,4,9–11] Previous research has found the vertical jump to be a reliable predictor of success in a number of sports, including American football,[12] soccer,[8] ice hockey[12,13] and many others.[2,9,10] The influence that strength has upon the vertical jump and associated characteristics should not be underestimated. Strong correlations have been found between the one repetition maximum squat,[14] isometric mid-thigh clean pulls,[4] and power during countermovement (CMJ) and static (SJ) vertical jumping.[3] Furthermore, training-induced increases in measures of maximum strength have been shown to result in vertical jump height and power output increases.[4,15]

Performing a vertical jump requires a certain level of force (ie, strength) production to elicit a successful maximum effort movement; performing a vertical jump under a loaded condition requires additional strength. From a sport perspective, it is possible that the athlete will encounter additional resistances similar to those used in the weighted vertical jump, such as wearing sporting equipment, collisions with other players, throwing implements, and the like. Within sport, it is clear that athletes can encounter a wide variety of external forces, and the athlete must overcome these forces to be successful.[3,8] Therefore, it becomes apparent that success in sport is often coupled with high levels of strength.[2,4,5,7] Not only does the vertical jump demand high levels of force output, but this force must be exerted at a rapid rate to induce the best performances.[17,19,22] This observation indicates that rate of force development (RFD) is an important aspect of explosive strength movements, such as jumping with and without a load.[3] To develop force characteristics, including explosiveness, unweighted and weighted jumping are commonly used during the training process for many sports, and are also used for the testing of these sports.[9,10,14,21]

Underlying characteristics of performance, such as strength, are often monitored and assessed to indicate an athlete's level of preparedness as well as to discern the degree of training adaptation. Previous studies have used various measures, which have included isointertial as well as isokinetic devices,[2,17] to identify strength and associated characteristics. There are always limitations to the use of these methods when determining relationships between strength characteristics, vertical jumping, and sports performance.[10] However, it is probable that the methods used to determine relationships between strength and sports performance must have a high degree of specificity to draw appropriate conclusions.[10] Thus, the use of testing methods sharing characteristics of a specific sport performance are necessary for the proper application of testing results.[10] A strength-testing method that does appear to share appropriate characteristics (eg, position, magnitude, and RFD) is the isometric mid-thigh clean pull using a force plate.[4,10,16] Furthermore, for strength and conditioning professionals, the monitoring of vertical jump height responses under various loading conditions may be a practical assessment tool that is specific to the characteristics observed in sport. Therefore, the primary purpose of the current investigation was to examine the relationships between isometric force time-curve characteristics and markers of unloaded and loaded vertical jump performance.

Methods

Experimental Design

The current investigation was a hypothesis-generating study with appropriate accompanying statistics.[18] Testing was performed as part of a previously established athlete-monitoring program. Testing included SJ, CMJ, and isometric mid-thigh clean pulls. Before the testing day, bar heights for the isometric mid-thigh clean pulls were obtained, athletes were familiarized with the vertical jumps and isometric mid-thigh clean pull procedures. Maximal effort testing was conducted in one session beginning with biometric data collected upon arrival, followed by the vertical jumps, a 3-min rest period, and isometric mid-thigh clean pulls.

Subjects

Forty-one female and twenty-two male Division I collegiate athletes active in track and field, tennis, softball, soccer, and volleyball participated in this study. In accordance with the guidelines of East Tennessee State University's Institutional Review Board, participants read and signed written informed consent documents pertaining to the long-term athlete-monitoring program and all testing procedures.

Before vertical jump and isometric clean pull testing, biometric data including height (cm), body mass (kg), and body composition were assessed. Height was measured using a stadiometer and recorded to the nearest 0.1 cm. Body mass and body composition measures were determined using an electronic scale and BodPod air displacement plethysmography instrumentation (Life Measurement Inc, Concord, CA), with standard procedures using an estimated thoracic gas volume. As a group ($n = 63$), characteristics were as follows: age = 19.9 ± 1.3, height = 172.8 ± 7.7 cm, body mass = 72.9 ± 19.6 kg, allometrically scaled body mass = 17.7 ± 3.0 $kg^{0.67}$, and percentage body fat = 19.2 ± 7.8.

Testing Methods

Vertical Jump Testing Procedures. A standardized warm-up procedure was followed for all participants before vertical jump and strength testing.[4] Athletes performed twenty-five jumping jacks and then a series of clean pulls, including one set of five clean pulls at the mid-thigh with an empty barbell (20 kg, Werksan Inc, Turkey), and three sets of three clean pulls at mid-thigh with 40 to 80 kg for women (depending upon sport) and 40 to 100 kg for men (depending upon sport). Jumps consisted of two types: SJ and CMJ. Each jump was performed with a load of 0 kg (PVC pipe) or 20 kg (barbell) placed upon the shoulders of the athletes between the seventh cervical vertebra and the third thoracic vertebra.[3,14,19] Approximately 1 min of rest was given between jumps; athletes performed two unloaded practice jumps, one at 50% perceived effort and one at 75% perceived effort, for both the SJ and CMJ, before the maximal effort tests began.

Vertical jump tests began with the SJ condition. Previous investigation from our laboratory has indicated no order effect of SJs vs CMJs.[20] Furthermore, the data were collected as part of an athlete-monitoring program in which the data are collected in a standard order.[10] Athletes performed all jumps on a force plate (Rice

Lake Weighing Systems, Rice Lake, WI) that had a sampling rate of 1000 Hz, with a smoothing half-width moving average rectangular filter. Upon stepping onto the force plate, athletes were instructed to get in the "ready position," which consisted of the athlete firmly holding the PVC pipe (0 kg) or barbell (20 kg) and assuming a squat position with a 90° knee angle measured with a handheld goniometer. Once in position, a countdown of "3, 2, 1 Jump" was given. A 3-s hold of the bottom position was used to eliminate the involvement of the stretch-shortening cycle.[16] Two trials of each jump condition (SJ 0 kg and SJ 20 kg) were completed with 1 min of rest between each trial. Upon completion of the SJ trials, athletes were provided with a timed rest period of 3 min before moving on to the CMJ trials.

Countermovement jumps were performed using standard procedures outlined in previous research.[16] Countermovement jumps were performed without a pause to a self-selected countermovement depth. Athletes were allowed two trials for each jump condition (0 kg and 20 kg), with 1 min of rest between trials. If any SJ or CMJ was perceived to be less than maximal effort by the investigators or athlete, the jump trial was repeated.

Vertical jump height (JH) was calculated from flight time (FT), as described in previous studies.[8,14,29] All SJ and CMJ force-time curve characteristics were recorded and analyzed using LabView 8.0 software (National Instruments, Upper Saddle River, NJ). Jump height difference was calculated as a percent loss from the average jump height achieved under 0-kg loading conditions with [Percent Loss = (Jump Height at 0 kg − Jump Height under 20 kg) ÷ Jump Height at 0 kg × 100].

Isometric Strength Testing Procedures. Following the vertical jump tests, athletes were provided with a rest period of approximately 3 min before the isometric mid-thigh clean pulls. All pulls were performed in a custom-designed rack over a force plate (Rice Lake Weighing Systems) with a sampling rate of 1000 Hz. The isometric mid-thigh testing apparatus is presented in Figure 1 along with the standard position as described by Haff et al.[16] Athletes used lifting straps and were taped to the bar to ensure that grip strength was not a factor in testing (Figure 1). Each athlete was provided two warm-up pulls, one at 50% and 75% perceived effort, separated by 45 s of rest. Following warm-up procedures, athletes were instructed to pull as fast and as hard as possible; this instruction has been previously found to produce optimal testing results.[7,16] Athletes began their maximal effort pull following the countdown "3, 2, 1." One minute of rest was given between the two maximal effort pulls. If the athlete or investigator perceived the pulls to be less than maximal effort or there was a greater than 250-N difference between the first and second pull, a third attempt was performed. The two best isometric mid-thigh clean pulls were averaged and used for analysis. The isometric mid-thigh clean pull was chosen based upon previous investigations indicating excellent reliability and high correlation with a wide variety of sports-related performances including vertical jumps.[4,7,19,21,23]

Variables calculated from the force-time curve included isometric peak force (IPF); isometric rate of force development (IRFD), and the forces at 50 ms (F50), 90 ms (F90), and 250 ms (F250). These force values (F50, F90, and F250) were chosen because of their potential relationship to forces produced during striking,[10,29] sprinting,[30] and jumping.[3,5,10] LabView 8.0 software (National Instruments) was used during testing, recording, and force-time curve analysis. Maximal strength measures were

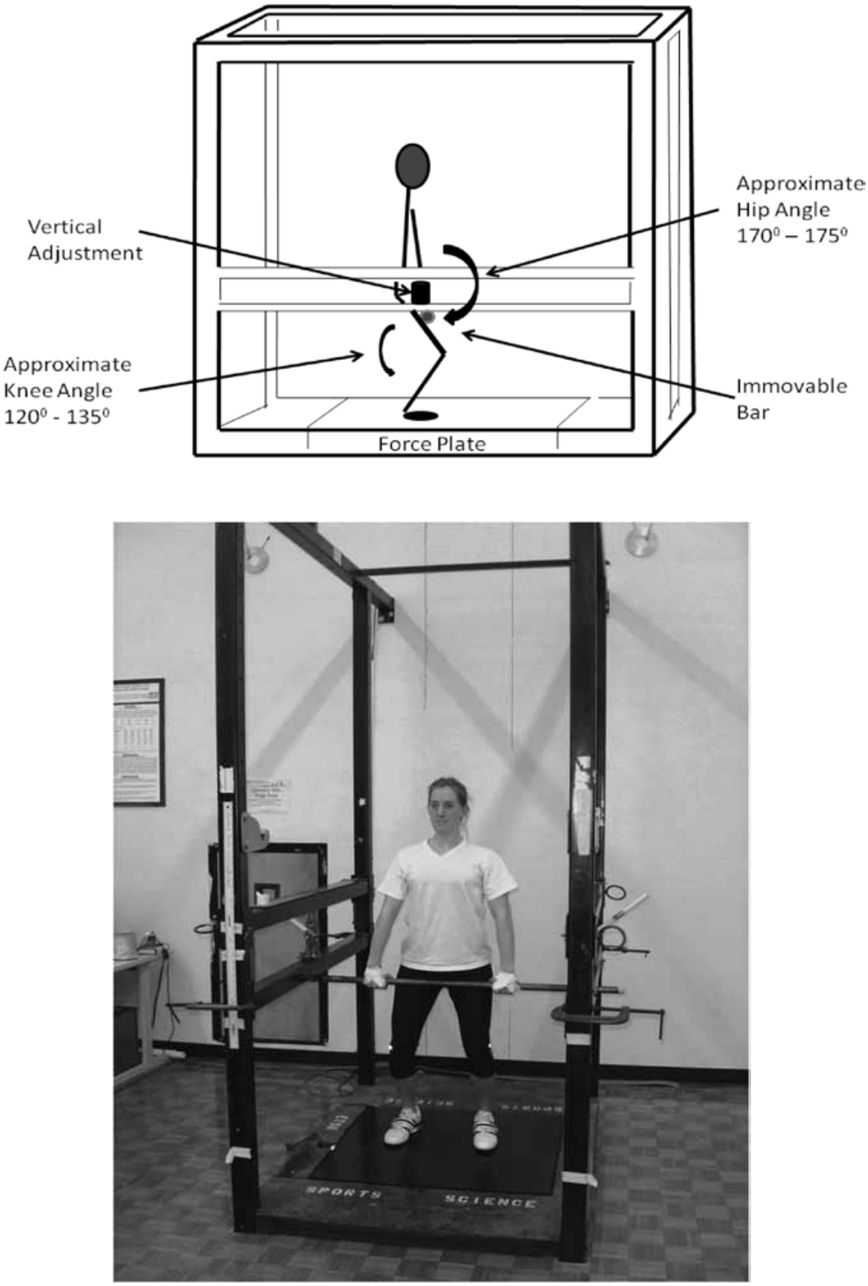

Figure 1 — Isometric mid-thigh clean pull testing. Top: schematic isometric mid-thigh clean pulls. Bottom: Photographic representation of isometric mid-thigh clean pulls.

evaluated in both absolute and normalized values. Previous literature has indicated that scaling forces allometrically appears to control for sex differences between athletes[7,14,21] Furthermore, data analysis of percent decrease in weighted and unweighted jumps showed no sex differences (analysis not shown). Forces were normalized according to the following allometric scaling expresssion: Absolute Force/(Body Mass (kg)$^{0.67}$).[7]

Statistical Analysis

Data from this investigation were reported as means ± standard deviations and analyzed using SPSS (version 13.0, SPSS, Inc. Chicago, IL). Vertical jump and isometric pull trial reliabilities were determined using ICC_{alpha} (ICCα). Jump height ICCα was SJ 0 kg $\alpha = 0.960$, SJ 20 kg $\alpha = 0.990$, CMJ 0 kg $\alpha = 0.970$, CMJ 20 kg $\alpha = 0.990$. The ICCα for all isometric mid-thigh clean pull variables were IPF $\alpha = 0.99$, F50 $\alpha = 0.79$, F90 $\alpha = 0.98$, F250 $\alpha = 0.94$, IRFD $\alpha = 0.86$. Relationships between variables were assessed using a Pearson correlation coefficient. Strength of relationships was qualitatively assessed using the following criteria: trivial ($r < .001$), small ($r = .1$ to 0.2), moderate ($r = .3$ to 0.4), and strong ($r = .5$ to 0.6), very strong ($r = .7$ to 0.8), nearly perfect ($r = .9$), and perfect ($r = 1.0$). The criterion for statistical significance of these relationships was $r = .25$, $P \leq .05$.

Additional analyses included comparisons of the strongest to the weakest athletes with respect to jump height and isometric strength testing variables. This additional analysis was performed to assist in confirming the primary findings of the study. Based on allometrically scaled isometric peak force (IPF_a), athletes were grouped into the strongest (n = 6) 5% of men (n = 3) and 5% of women (n = 3) and then compared with the weakest (n = 6) 5% of men (n = 3) and women (n = 3). Two-tailed independent samples *t* tests were used to assess differences between means of the strong and weak groups (strong group $IPF_a = 232.4 \pm 28.4$ N/kg$^{0.67}$, weak $IPF_a = 123.2 \pm 18.9$ N/kg$^{0.67}$, ($P \leq .05$). Values from *t* tests were reported with Holm's sequential Bonferroni[24] method of controlling for type I errors. Cohen's effect sizes (d) were also calculated according to the formula Cohen's $d = M_1 - M_2/\sigma_{pooled}$, where $\sigma_{pooled} = \sqrt{[(\sigma_1^2 + \sigma_2^2/2)]}$. Effect sizes are described by Cohen[25] as small ($d \leq 0.2$), moderate ($d = 0.2$ to 0.8), and large ($d \geq 0.8$).

Results

Unweighted Jumping and Strength Characteristics

All Pearson correlation coefficients are presented in Table 1. Moderate correlations ($P \leq .05$) were found between SJ 0 kg height and IPF ($r = 0.40$), IPF_a ($r = 0.47$), F50 ($r = 0.33$), $F50_a$ ($r = 0.33$), F250 ($r = 0.39$), $F250_a$ ($r = 0.42$), IRFD ($r = 0.49$). The correlations between SJ height with 0 kg and F90 ($r = 0.21$, $P > .05$), $F90_a$ ($r = 0.13$, $P > .05$) were not statistically significant.

There were moderate ($P \leq .05$) correlations between CMJ height 0 kg and IPF ($r = 0.36$), IPF_a ($r = 0.41$), F250 ($r = 0.34$), $F250_a$ ($r = 0.34$), and RFD ($r = 0.43$). There were weak, statistically significant correlations between CMJ height 0 kg and F50 ($r = 0.27$) and $F50_a$ ($r = .26$). The correlations between the SJ height 0 kg and F90 ($r = 0.21$), $F90_a$ ($r = 0.13$) were not statistically significant ($P > .05$). The correlations between both CMJ height 0 kg and F90 ($r = 0.19$), $F90_a$ ($r = 0.11$) were not statistically significant ($P > .05$).

Table 1 Correlations between isometric force-time measures and vertical jumps under various loading characteristics

Vertical Jump Height vs Force Characteristics	IPF	IPF_a	F50	$F50_a$	F90	$F90_a$	F250	$F250_a$	IRFD
Static Jump Height 0 kg	0.40*	0.47*	0.33*	0.33*	0.21	0.13	0.39*	0.42*	0.48*
Static Jump Height 20 kg	0.55*	0.52*	0.52*	0.48*	0.37*	0.24	0.56*	0.51*	0.66*
Countermovement Jump Height 0 kg	0.36*	0.41*	0.27*	0.26	0.19	0.11	0.34*	0.34*	0.43*
Countermovement Jump Height 20 kg	0.55*	0.52*	0.50*	0.45*	0.33*	0.48*	0.54*	0.48*	0.62*

Note. *Statistically significant, $P < .05$. Abbreviations: IPF = isometric peak force (N), IPF_a = isometric peak force allometrically scaled ($N/kg^{0.67}$), F50 = force at 50 ms (N), $F50_a$ = force at 50 ms allometrically scaled ($N/kg^{0.67}$), F90 = force at 90 ms, $F90_a$ = force at 90 ms allometrically scaled ($N/kg^{0.67}$), F250 = force at 250 ms, $F250_a$ = force at 250 ms allometrically scaled ($N/kg^{0.67}$), IRFD = isometric rate of force development (N/s).

Weighted Vertical Jumping and Strength Characteristics

There were moderate-to-strong ($P \leq .05$) correlations between SJ height 20 kg and IPF ($r = 0.55$), IPF_a ($r = 0.52$), F50 ($r = 0.52$), $F50_a$ ($r = 0.48$), F90 ($r = 0.37$), F250 ($r = 0.56$), $F250_a$ ($r = 0.51$), and IRFD ($r = .66$). Moderate-to-strong ($P \leq .05$) correlations were found between CMJ 20 kg height and IPF ($r = 0.55$), IPF_a ($r = 0.52$), F50 ($r = 0.50$), $F50_a$ ($r = 0.45$), F90 ($r = 0.33$), F250 ($r = 0.54$), $F250_a$ ($r = 0.48$), and IRFD ($r = .62$).

Jump Height Differences and Strength Characteristics

Moderate ($P \leq .05$), negative correlations were observed between percent loss in SJ height and IPF ($r = -0.40$), F50 ($r = -0.45$), $F50_a$ ($r = -0.37$), F90 ($r = -0.36$), F250 ($r = -0.43$), and IRFD ($r = -0.41$) and a weak negative relationship with $F250_a$ ($r = -0.29$). There was no statistically significant relationship between percent decrease in SJ height and $F90_a$ ($r = -0.25$, $P > .05$).

Moderate-to-strong ($P \leq .05$) relationships were found between percent loss in CMJ height and IPF ($r = -0.49$), IPF_a ($r = -0.33$), F50 ($r = -0.53$), $F50_a$ ($r = -0.45$), F90 ($r = -0.32$), F250 ($r = -0.50$), $F250_a$ ($r = -0.37$), and IRFD ($r = -0.51$). There was no statistically significant relationship between percent loss in CMJ height and $F90_a$ ($r = -0.18$, $P > .05$). Percent loss in jump height correlations are presented in Table 2.

Strong Athlete Group and Weak Athlete Group Comparisons

Differences between strong athlete and weak athlete group means are presented in Table 3 and 4. Statistically significant differences were found between groups on the following performance variables: percent decrease in SJ height, percent decrease in CMJ height, IRFD, F50, $F50_a$, F90, $F90_a$, F250, and $F250_a$. The strong group had a greater IRFD, F50, $F50_a$, F90, $F90_a$, F250, and $F250_a$ than the weak group. The weak

Table 2 Correlations between isometric force-time values and jump height decreases

Percent Decrease in Jump Height vs Force Characteristics	IPF	IPF_a	F50	$F50_a$	F90	$F90_a$	F250	$F250_a$	IRFD
Percent Decrease Jump SJ Height	–0.40*	–0.24	–0.4*	–0.3*	–0.3*	–0.25	–0.43*	–0.29	–0.41*
Percent Decrease Jump CMJ Height	–0.49*	–0.3*	–0.5*	–0.4*	–0.3*	–0.18	–0.50*	–0.37*	–0.51*

Note.*Statistically significant, $P < .05$. Abbreviations: IPF = isometric peak force (N), IPF_a = isometric peak force allometrically scaled ($N/kg^{0.67}$), F50 = force at 50 ms (N), $F50_a$ = force at 50 ms allometrically scaled ($N/kg^{0.67}$), F90 = force at 90 ms, $F90_a$ = force at 90 ms allometrically scaled ($N/kg^{0.67}$), F250 = force at 250 ms, $F250_a$ = force at 250 ms allometrically scaled ($N/kg^{0.67}$), IRFD = isometric rate of force development (N/s).

Table 3 Comparisons between strongest and weakest athletes (mean ± SD)

Variable	Strong Group (n = 6)	Weak Group (n = 6)	*P*	*d*
SJ 0-kg Jump Height (cm)	30.75 ± 9.68	23.67 ± 4.89	0.15	0.92
SJ 20-kg Jump Height (cm)	25.39 ± 8.31	16.69 ± 4.81	0.06	1.28
Percent Decrease in SJ Height	*17.79 ± 3.44	30.40 ± 7.8	0.01	2.10
CMJ 0-kg Jump Height (cm)	33.53 ± 10.75	28.27 ± 6.34	0.33	0.60
CMJ 20-kg Jump Height (cm)	27.57 ± 8.64	18.68 ± 5.31	0.06	1.24
Percent Decrease in CMJ Height	*17.37 ± 4.81	34.45 ± 7.76	0.002	2.65

Note. *Statistically different Holm's sequential Bonferroni adjusted *P* value. Abbreviations: SJ = static jump, CMJ = countermovement jump, *d* = effect size.

Table 4 Differences in force-time curve variables between strongest and weakest athletes (mean ± SD)

Variables	Strong Group (n = 6)	Weak Group (n = 6)	*P*	*d*
Force at 50 ms (N)	*2,083 ± 616	837 ± 230	0.003	2.68
Force at 90 ms (N)	*2,787 ± 895	849 ± 203	0.003	2.99
Force at 250 ms (N)	*4,100 ± 971	1,535 ± 329	0.001	3.54
F 50 ms Allometrically Scaled ($N/kg^{0.67}$)	*86 ± 24	47 ± 10	0.008	2.12
F 90 ms Allometrically Scaled ($N/kg^{0.67}$)	*115 ± 36	49 ± 15	0.005	2.36
F 250 ms Allometrically Scaled ($N/kg^{0.67}$)	*167 ± 49	85 ± 18	0.008	2.23
Rate of Force Development ($N{\cdot}s^{-1}$)	*12,175 ± 4,338	3,243 ± 899	0.003	2.85

Note. *Statistically different Holm's Sequential Bonferroni adjusted *P* value, (*d*) effect size.

group had a larger decrease in SJ height and CMJ height under weighted conditions than the strong group. There were no statistically significant differences between strong and weak groups in SJ height at 0 kg, SJ height at 20 kg, CMJ height at 0 kg, and CMJ height at 20 kg. Strong and weak group mean comparisons, standard deviations, *P* values, and effect sizes are presented in Table 3 and 4.

Relationship of IPF to RFD

As expected, there was a very strong correlation between IPF and IRFD ($r = .88$, $P \leq .05$), which agrees with previous literature.[10,26] Additionally, IPF showed moderate-to-strong correlations with F50 ($r = .85$), F90 ($r = .42$), and F250 ($r = .93$). These relationships agree with the observation that stronger athletes had higher IRFDs and greater instantaneous forces (Table 4).

Discussion

There are three important findings associated with the current investigation. The first is the strong relationships between maximum strength (IPF), IRFD, and F50, F90, F250. Maximum isometric strength has been previously associated with RFD in several studies.[17,26] It is unclear exactly why increased maximum strength is associated with increased RFD, but it may be related to alterations in the H-reflex.[27]

Second is the association of maximum strength characteristics (eg, IPF, IRFD) with jump capabilities. Newton's second law indicates that greater forces will result in greater accelerations. As acceleration increases the required forces also increase; therefore, achieving high velocities, power outputs, and jump heights is dependent upon high force production.[10] Data indicates that the critical time periods for foot contact in the vertical jump (no steps) appears to be 250 to 300 ms.[28] Previous literature has found strong relationships between isometric measures of strength and dynamic performance measures, including the vertical jump.[3,4,10,21] Assuming that the isometric measures are indicative of striking,[10,29] sprinting,[30] and vertical jumping[3,5,10] (ie, force at 50, 90, and 250 ms), then stronger athletes measured in this manner may produce superior results. Interestingly, athletes with higher jumps, both SJ and CMJ, also produced more force at the key time intervals of 50 ms, 90 ms, and 250 ms in the current study. Indeed, this last finding would indicate that stronger athletes may produce higher forces over the duration of the jump. Thus, the results of the current study agree with previous literature that indicated that isometric measures are related to jumping[16,21] and that better jumpers are also stronger and more explosive athletes.[5] This relationship was most apparent during the CMJ condition; however, some literature indicates a stronger relationship to the static jump.[16] The authors believe that the stronger relationship may exist with the CMJ condition owing to the nature of the training backgrounds of the athletes tested as well as the additional involvement of the stretch-shortening cycle in training and in their sport.

The third important finding is the observation that stronger athletes have smaller decrements in vertical jump heights associated with weighted jumps compared with weaker athletes. There are several potential reasons for these observations. Training studies have produced increases in neural drive (IRFD) associated with adaptations in the contractile strength of skeletal muscle.[17] Furthermore, athletes that are found to be more explosive, which may be strongly related to their nervous system capabilities, are often found to possess high levels of strength.[3–5,7,10,21] Thus, maximum strength appears to be an important underlying factor that influences both unweighted and weighted jumping.[3,5,8] Though not directly measured in the current investigation, previous literature indicates that additional considerations must be given to mechanisms involving a shorter amortization phase,[10] producing larger forces over the course of the jump,[9] and simply being able to better overcome the additional load.[3–5,10] It is possible that maximum strength levels influence these mechanisms in a positive manner.

The results of this study indicate that stronger athletes perform better than weaker athletes during a vertical jump. When comparing strong athletes to weak athletes, it is clear that the stronger athletes are more explosive, show smaller decrements in jump height under loaded conditions, and will be more likely to produce higher forces at critical times. The results of these comparisons make it clear that strength affects performance and should not be overlooked as an important characteristic for explosive performance. Both strength and explosiveness (IRFD) were found to be related to the jump heights of both SJ and CMJ. These relationships were observed among athletes jumping without an additional load, as well as with the load. These findings indicate that strength and explosiveness are not only related to jumping with an additional load, but also when an athlete is challenged with their own body mass.

Practical Application

The ability to apply research findings to advanced athletes is often a challenge, as much of the scientific literature reports on untrained or novice subjects. However, the current investigation has evaluated a trained group of Division I athletes from a variety of sporting backgrounds. The results indicate that a measure of maximum strength is related to greater explosiveness (eg, IRFD, instantaneous forces). Furthermore, strength and explosiveness (IRFD) were found to be related to the jump heights of both SJ and CMJ.

The results from the current investigation indicate that the ability to produce greater IPF, force at 50 ms, 90 ms, 250 ms, and IRFD is related to jump height. Data also indicate that these variables are also related to smaller decrements in weighted CMJ and SJ heights. The additional comparison of strong vs weak athletes emphasizes the importance of strength to athletic performance. Therefore, stronger athletes jump higher and have smaller decreases in jump height with additional loading. In addition, the current investigation suggests that a weighted jump may be a practical method of assessing the relative strength levels of various athletes, although more study is necessary.

Results of this study also suggest that coaches should consider the potential importance of strength and IRFD during movements involving static starts or heavy eccentric loading such as a CMJ. Training programs aimed toward the enhancement of maximal concentric and eccentric strength, as well as the rate at which force is produced, may potentially enhance the performance of dynamic movement under conditions requiring large changes in inertia and large eccentric forces.

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