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Original Research

Relationship Between Mechanical Variables and Maximum Strength in Countermovement and Pure Concentric Pull-Ups Among Male Collegiate Athletes

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Abstract

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Recent studies have verified the use of the stretch-shortening cycle (SSC) during countermovement pull-ups (CMPs); however, the relationship between CMP performance and maximal strength remains unclear. With the increasing popularity of training guided by mechanical variables, quantifying SSC-related contributions and identifying key CMP variables may provide insights into innovative pull-up training. This study examined correlations between mechanical variables during CMPs and pure concentric pull-ups (PCPs) and maximal muscle strength in athletes, to elucidate the characteristics of CMPs. Fifty male collegiate athletes participated. A linear position transducer measured peak velocity (Vmax), mean velocity (Vmean), mean power, and time to peak velocity (time to Vmax) during CMPs and PCPs. Lat pulldown isometric maximal strength (LP-IMS) was evaluated using a hand-held dynamometer. To control for body weight, residuals from regressions with body weight as the independent variable were analyzed. Spearman's rank correlation coefficients were calculated to evaluate relationships between mechanical variables and maximal strength. Vmean (r_s = 0.511) and Vmax (r_s = 0.544) of PCPs exhibited significant strong positive correlations with LP-IMS, whereas time to Vmax correlated moderately negatively (r_s = -0.319). Conversely, CMP Vmean demonstrated a weak positive correlation with LP-IMS (r_s = 0.279), with no significant correlation for Vmax. CMP time to Vmax was strongly negatively correlated with LP-IMS (r_s = -0.570). These findings indicate that Vmax and Vmean in CMPs are weakly associated with strength, suggesting the involvement of non-strength factors, such as SSC utilization. This study provides insights into upper-limb SSC and may guide training protocols for pulling exercises.

Keywords: Plyometric, upper limb, stretch-shortening cycle, velocity-based training

Introduction

In rotational joint movements, countermovement refers to an initial movement in the opposite direction immediately preceding the primary motion. Countermovements have long been investigated as a means to enhance athletic performance in the field of sports science.[1,2,3] A key contributing factor to this enhancement is the utilization of the stretch-shortening cycle (SSC), which improves force and power output.[4] While extensive studies have been conducted on the lower-limb SSC, investigations focusing on the upper limb SSC remain limited.[5,6] However, the upper limb SSC reportedly contributes to force and power generation in various sports.[5,7] Among studies on the upper limb SSC, countermovement has been examined in pushing

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exercises, such as bench throws and explosive push-ups.[8,9] Pulling movements are also crucial in sports performance, as they play a fundamental role in many athletic activities.[10,11] Despite their importance, research on the application of countermovements in pulling exercises remains limited.

Pull-ups contribute to the development of upper body strength and are effective for enhancing the strong pulling force required in various sports. They are also included in physical fitness tests in United States military academies, underscoring their practical significance.[12] Recent research on pull-ups using a dedicated vertical platform has shown that countermovement pull-ups (CMPs) result in greater ascent velocity than pure concentric pull-ups (PCPs).[13] However, the abovementioned research allowed coordination between the lower limbs and trunk, rendering it unclear whether the observed effects were specific to the upper limbs. As the study participants were limited to climbers, further investigations involving a broader athletic population are necessary to evaluate CMPs for general athletes. Although PCP studies have reported a strong correlation between maximal strength and mean velocity, the relationship between maximal strength and CMPs remains unclear.[14] Recent training methodologies incorporate mechanical variables, including velocity and time, using devices such as linear position transducers to enhance athletic performance and strength development.[15,16]

In this context, examining how mechanical variables in CMPs and PCPs correlate with maximal strength and identifying the differences in these correlations are essential for evaluating CMPs as a novel training method for pulling exercises utilizing countermovements. Such an investigation could provide new insights into the study of SSC in upper limb pulling movements.

Therefore, the purpose of this exploratory study was to examine the correlations between mechanical variables and maximal strength in CMPs and PCPs among athletes and to clarify the unique characteristics of CMPs based on these correlations.

Methods

Participants

The sample size required for this study was determined using an a priori power analysis in G*Power software (version 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), according to Faul et al.[17] This study was exploratory in nature, and no closely related studies have employed the same variables and statistical methods to provide empirical estimates of the expected correlation; hence, the effect size was determined with reference to Cohen's conventional criteria.[18] Moreover, the minimum detectable effect considered practically meaningful was set a priori at $r = 0.50$. The statistical power was evaluated with a two-tailed $\alpha = 0.05$. Under these conditions, with a desired power $(1-\beta)$ of 0.90, the required sample size was estimated to be 38 participants.

Although this study employed a nonparametric Spearman rank correlation analysis, Spearman's ρ is mathematically equivalent to the Pearson correlation coefficient of the ranked data,[19] and the use of the Pearson model for statistical power approximation in correlation analyses has been widely validated.[17,20] Moreover, the difference introduced by ranking is theoretically minimal under the assumption of a monotonic relationship.[21] Therefore, the use of a parametric correlation model for statistical power approximation was considered appropriate for this study.

Participants were publicly recruited via an online announcement, and participation in the study was voluntary. All participants were male collegiate athletes from the same university. The selection criteria for participants were (1) a minimum of 3 years of continuous resistance training and (2) the ability to perform at least 10 pull-ups. Individuals meeting these criteria were defined as athletes. Consequently, 50 participants (18 swimmers, 16 throwers, and 16 volleyball players) who identified as men were selected (mean ± standard deviation: age 20.1 ± 1.2 years, height 1.76 ± 0.07 m, weight 77.4 ± 15.4 kg). As this number exceeded the required sample size of 38, sufficient statistical power was achieved.

All participants were informed of the purpose of the study, measurement procedures, and potential risks, and written informed consent was obtained. This study was approved by the Tokai Ethics Committee (approval number: 20148) and conducted in accordance with the ethical standards of the *International Journal of Exercise Science*.[22]

Protocol

A within-subject repeated measures design was adopted to ensure consistency by standardizing the measurement procedures according to a uniform protocol. Based on the results of a preliminary experiment, the procedures were simplified to complete the experiment within 30 min, thereby reducing the physical and psychological burdens of participants. To mitigate the effects of fatigue during the training phase or competition season, measurements were conducted within 1 week following the conclusion of each sport's main season. All trials were conducted indoors between 16:00 and 20:00 h on the same day. Participants were instructed to abstain from upper body strength training and intense physical activity for 24 h prior to testing.

Before the warm-up, a standardized instructional video was shown to ensure that participants fully understood the measurement procedures. The warm-up consisted of 10 min of cycling on an ergometer at 60% of the maximum heart rate, followed by two familiarization trials of each testing movement at approximately 50% of perceived maximal effort. The order of the trials was standardized as PCPs, CMPs, and lat pulldown strength tests—following the protocol of a previous study[13]—to minimize the influence of fatigue. Additionally, a 3-min rest period was provided after the warm-up and between each trial to suppress cumulative fatigue as much as possible. By strictly adhering to these procedures and unifying testing conditions, the consistency and reproducibility of this study were ensured.

Pull-up Protocol.

A Hammer Strength power rack (Life Fitness, Rosemont, IL, USA) was used for the pull-up measurements.

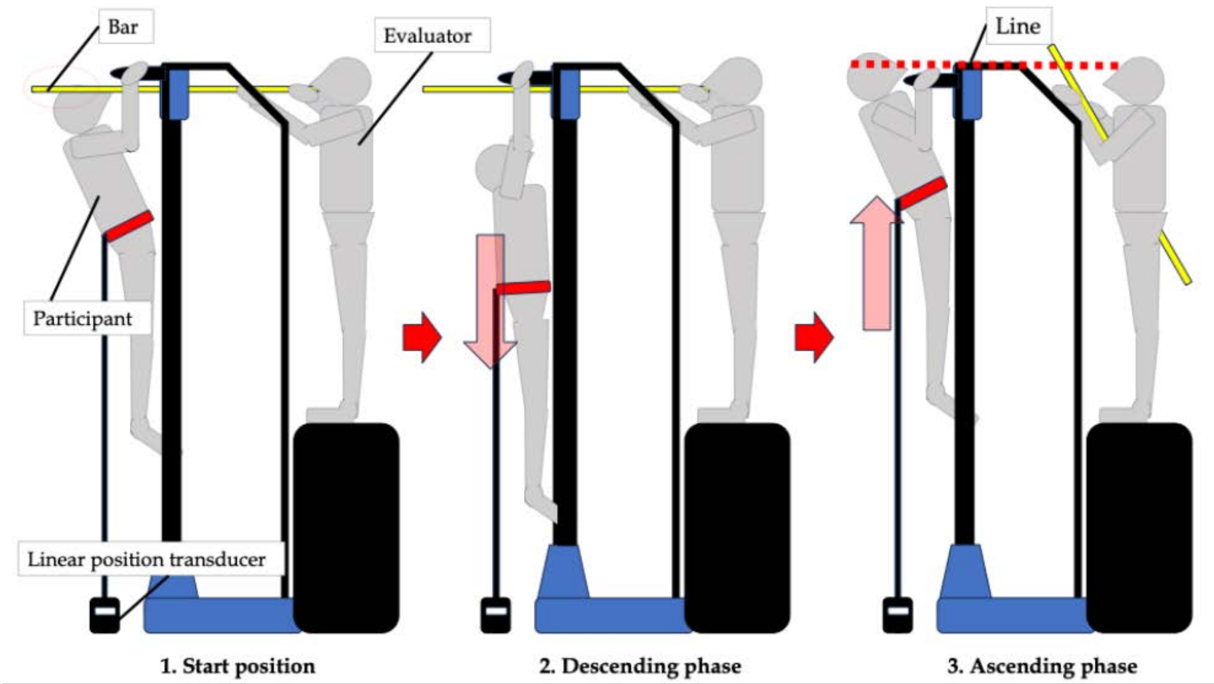
Pure Concentric Pull-up.

To evaluate pure concentric capability, participants performed PCPs. They were instructed to hang from the power rack while maintaining a vertical torso with fully extended arms. At the examiner's count, this position was maintained for 2 s before executing a single maximal upward pull in the vertical direction as quickly as possible. No specific restrictions were imposed on the descent phase, allowing participants to return to the starting position naturally.

Countermovement Pull-up.

Figure 1 illustrates the CMP procedure employed in this study. The starting position was defined as the point where the participant's head was at the same height as the grip of the power rack. To ensure precision, the examiner positioned a stick at the grip height, using the participant's head touching the stick as the reference starting position. This alignment was performed while the participants rested their feet on a safety bar to minimize fatigue. Subsequently, the participants lifted their feet off the safety bar and remained static for 2 s at the examiner's count. They fully relaxed their arms to achieve complete elbow extension, rapidly descending before immediately reversing direction to perform an explosive upward pull-up.

Figure 1. Countermovement pull-up.



A pronated grip was employed for all pull-up trials, with grip width standardized to shoulder width. To accurately assess upper limb strength characteristics, participants were strictly prohibited from using their lower limbs or torso for momentum (i.e., no kipping). Knee and hip joints were required to remain fully extended throughout the trials. Participants were also instructed to minimize excessive forward or backward torso movement. The trial was only considered valid if the body was pulled vertically and the nose clearly surpassed the height of the bar. Trial validity was determined according to predefined criteria shared in advance, and confirmed only after a consensus was reached by both evaluators certified by the National Strength and Conditioning Association with Certified Strength and Conditioning Specialist credentials. If an invalid trial occurred, a 3-min rest period was provided before retesting. These strict procedures were employed to ensure measurement reliability and reproducibility.

To assess the mechanical variables in CMPs and PCPs, a linear position transducer (SPEED4LIFTS S.L., Madrid, Spain) was used. The reliability of this device has been confirmed in previous studies.[23,24] The linear position transducer measured the peak velocity (Vmax), mean velocity (Vmean), mean power, and time to peak velocity (time to Vmax). The wire end of the linear position transducer was attached to a belt securely fastened at the L5 vertebral level to prevent loosening during measurement. The linear position transducer was positioned directly below the L5 vertebra, and adjustments were made before each trial to ensure that the wire remained vertical throughout the movement.

Data were collected using the Vitruve application (version 4.29.1; SPEED4LIFTS S.L., Madrid, Spain) via Bluetooth and transmitted in real time to a seventh-generation iPad tablet (Apple Inc., Cupertino, CA, version 15.5). All data were sampled at 100 Hz.

Maximum Strength Protocol.

Maximal strength was evaluated using an isometric lat pulldown. Isometric strength testing is a safe, reproducible method that minimizes the risk of injury and technical variability.[25,26] Testing was conducted at the end range of motion, corresponding to the maximal elbow extension position achieved at the turnaround of the descending phase in CMPs.

For the LP-IMS measurement, a lat pulldown machine (Nautilus Inc., 9NA-S3305, Washington, USA) and hand-held dynamometer (Mobie ZMT-201; Sakai Medical, Tokyo, Japan) were utilized. The hand-held dynamometer employed in this study follows the same calibration method as previous models, with its accuracy verified by an independent third-party. To ensure consistent isometric testing conditions, the dedicated strap of the hand-held dynamometer was attached to the cable outlet from which the bar was suspended, and the device was fixed 10 cm below the bar (Figure 2). The dynamometer was not connected to the weight stack cable but was set to a fixed anchor point. For all trials, the examiner confirmed that the strap was attached at the same position, thereby ensuring identical measurement conditions. Participants gripped the bar with the same pronated grip width as in the pull-up trials and maintained a depressed scapular position, with fully extended elbows, while keeping the torso vertical relative to the floor. The examiner ensured proper positioning by aligning the participant's torso, bar, and hand-held dynamometer attachment site in a straight line. Following the examiner's count, participants pulled the bar for more than 5 s while maintaining a vertical torso and avoiding momentum to ensure pure strength exertion. The peak force (N) measured by the hand-held dynamometer was recorded as the LP-IMS. Trials were deemed invalid if the participant failed to maintain a vertical torso or exhibited momentum-assisted movement. In such cases, a 3-min rest period was provided before a retest.

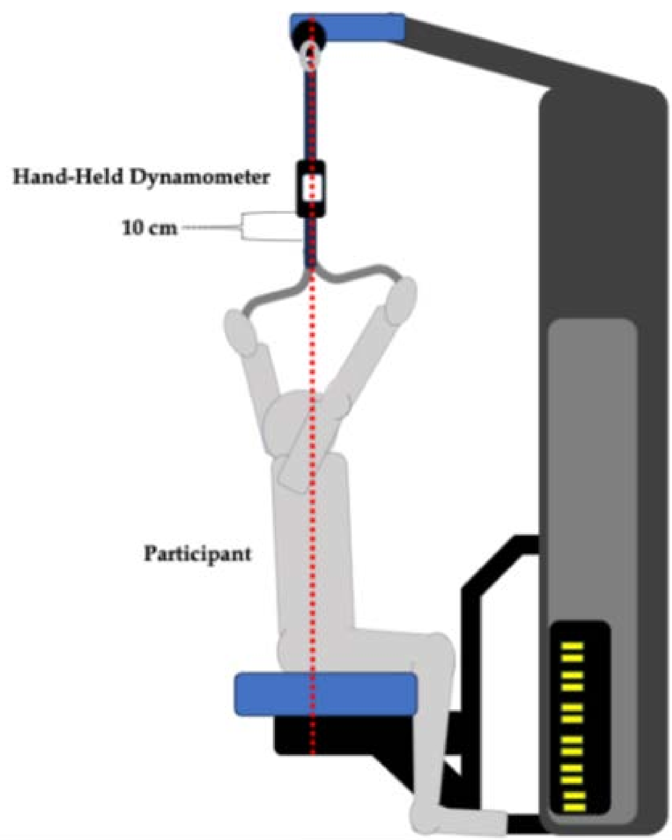


Figure 2. Lat pulldown isometric maximal strength.

Statistical Analysis

Body weight and additional load negatively correlate with pull-up repetition count and velocity.[14,26] Given these findings, we examined the correlation between body weight and each measured variable, revealing significant correlations between body weight and all mechanical variables.

To account for this effect, a simple regression analysis was performed for each variable, with body weight as the independent variable. The residuals from these regressions were defined as "body weight-adjusted values" and were used in subsequent analyses. Furthermore, when examining the correlation between these residuals and body weight, no significant correlation was identified, confirming that the influence of body weight was effectively removed.

The normality of the calculated residuals was assessed using the Shapiro–Wilk test, which revealed that several variables did not satisfy the assumption of normality. Therefore, to evaluate associations without relying on the assumption of normality, Spearman's rank correlation coefficient (r_s) was applied to all correlation analyses, allowing direct comparison of correlation coefficients and ensuring consistent interpretation across analyses. The strengths of the correlations were interpreted according to the criteria proposed by Hopkins et al.[27]: $r < 0.10$, trivial; $0.10 \le r < 0.30$, small; $0.30 \le r < 0.50$, moderate; $0.50 \le r < 0.70$, large; and $r \ge 0.70$, very large. All variables are reported as median [interquartile range]. Statistical analyses were performed using R software (version 4.3.2; R Core Team, 2023, R Foundation for Statistical Computing, Vienna, Austria), with the significance level set at $p < 0.05$.

Results

Table 1 presents all measurement results.

Table 1. Descriptive statistics of mechanical variables (median [IQR]) for CMPs, PCPs, and LP-IMS in collegiate athletes

Variable	**Median**	[	**IQR**	]
Weight (kg)	73.50	[	65.25–87.25	]
CMP Vmean (m/s)	0.70	[	0.57–0.79	]
CMP Vmax (m/s)	1.08	[	0.89–1.22	]
CMP MP (W)	491.92	[	448.76–545.16	]
CMP Time to Vmax (s)	0.24	[	0.13–0.38	]
PCP Vmean (m/s)	0.64	[	0.52–0.73	]
PCP Vmax (m/s)	1.06	[	0.84–1.19	]
PCP MP (W)	464.50	[	406.58–525.30	]
PCP Time to Vmax (s)	0.40	[	0.25–0.57	]
LP-IMS (N)	123.80	[	102.50–139.75	]

CMP, Countermovement pull-up; PCP, Pure concentric pull-up; LP-IMS, Lat pulldown isometric maximum strength; Vmean, Mean velocity; Vmax, Peak velocity; MP, Mean power; Time to Vmax, Time to peak velocity; SD, Standard deviation

Figure 3 illustrates the relationships between CMP and PCP Vmean and LP-IMS. PCP Vmean demonstrated a significant positive correlation with LP-IMS ($r_s = 0.51$, 95% confidence interval [CI] [0.25, 0.71], $p < 0.001$), whereas CMP Vmean also achieved significance, although the correlation was weak ($r_s = 0.27$, 95% CI [0.00, 0.53], $p = 0.04$).

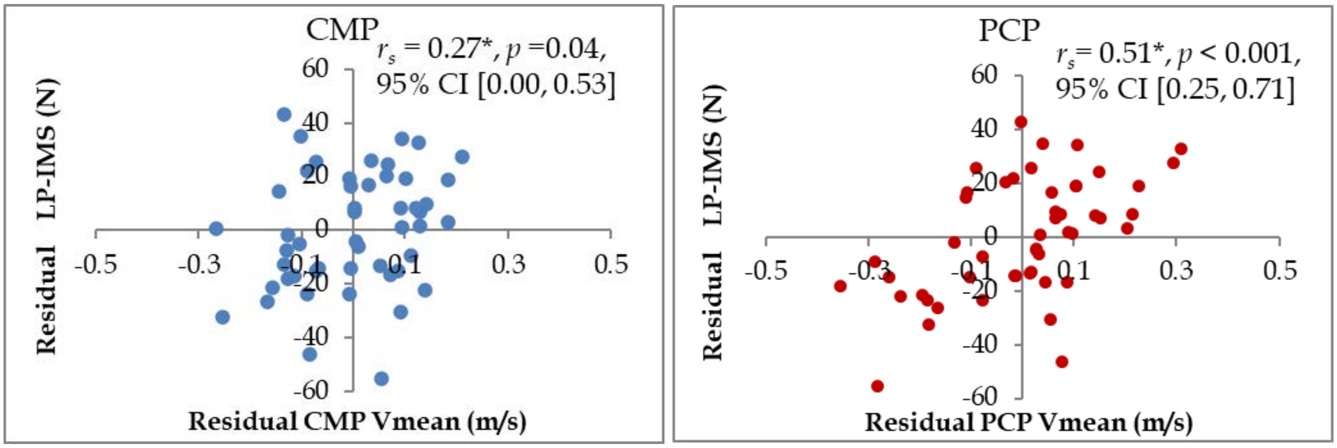


Figure 3. Scatterplots of weight-adjusted residual values for countermovement pull-up mean velocity (CMP Vmean) and pure concentric pull-up mean velocity (PCP Vmean) versus maximal muscle strength. Spearman's rank correlation coefficients (r_s) are reported with 95% confidence intervals (CIs) in parentheses; * = p < 0.05. LP-IMS, Lat pulldown isometric maximum strength.

Figure 4 shows the relationships between CMP and PCP Vmax and LP-IMS. PCP Vmax exhibited a significant positive correlation with LP-IMS (r_s = 0.54, 95% CI [0.27, 0.73], p < 0.001), whereas CMP Vmax did not exhibit a significant correlation (r_s = 0.20, 95% CI [-0.10, 0.49], p = 0.15).

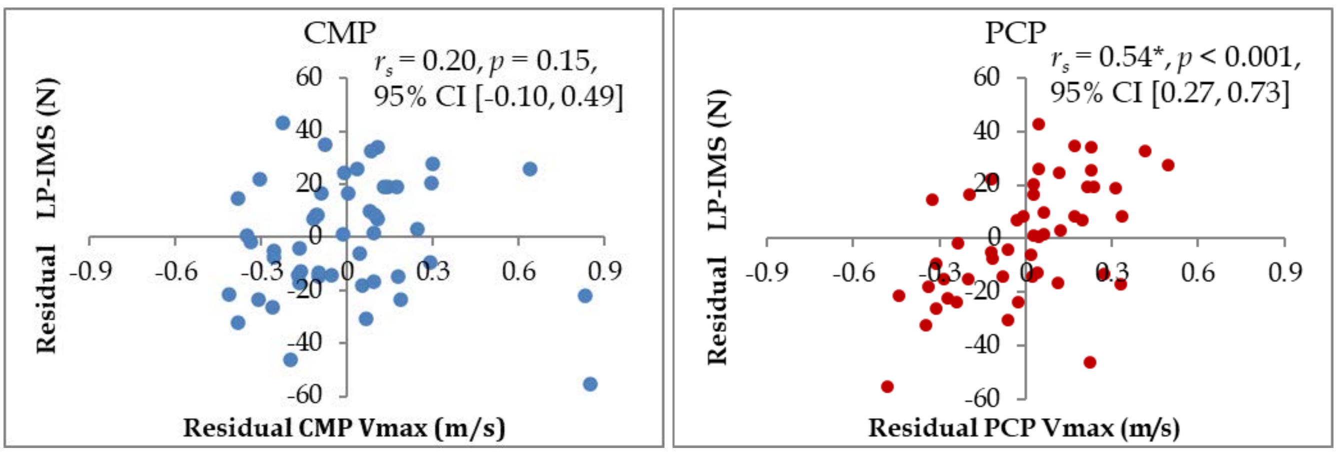


Figure 4. Scatterplots of weight-adjusted residual values for countermovement pull-up peak velocity (CMP Vmax) and pure concentric pull-up peak velocity (PCP Vmax) versus maximal muscle strength. Spearman's rank correlation coefficients (r_s) are reported with 95% confidence intervals (CIs) in parentheses; * = p < 0.05. LP-IMS, Lat pulldown isometric maximum strength.

Figure 5 shows the relationships between CMP and PCP time to Vmax and LP-IMS. PCP time to Vmax displayed a significant negative correlation with LP-IMS (r_s = -0.31, 95% CI [-0.55, -0.04], p = 0.02), whereas CMP time to Vmax demonstrated a significant negative correlation (r_s = -0.57, 95% CI [-0.74, -0.35], p < 0.001).

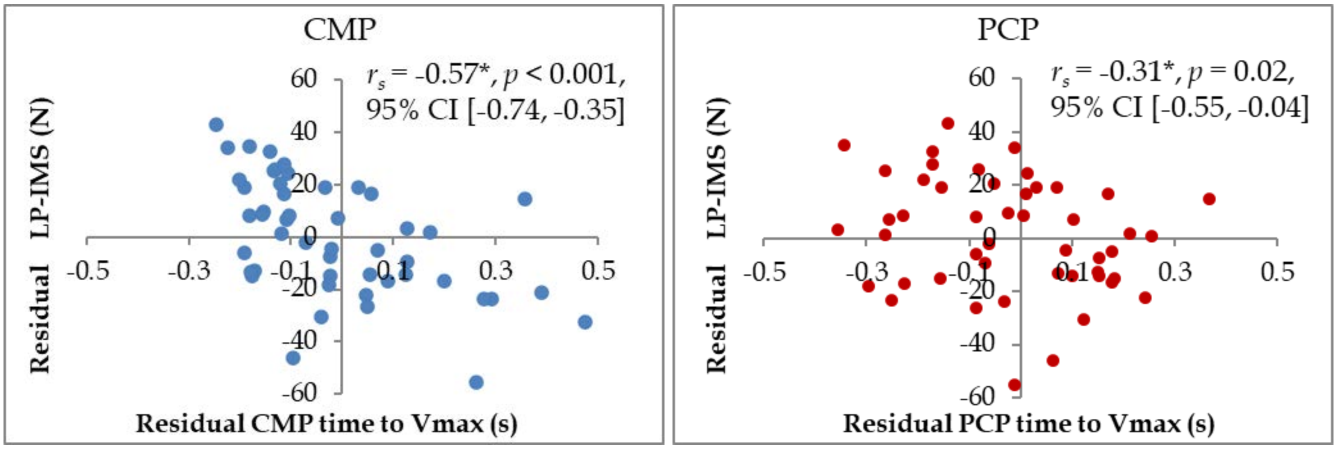


Figure 5. Scatterplots of weight-adjusted residual values for countermovement pull-up time to peak velocity (CMP time to Vmax) and pure concentric pull-up time to peak velocity (PCP time to Vmax) versus maximal muscle strength. Spearman's rank correlation coefficients (r_s) are reported with 95% confidence intervals (CIs) in parentheses; * = p < 0.05. LP-IMS, Lat pulldown isometric maximum strength.

Discussion

In this study, we aimed to examine the correlation between mechanical variables and maximal strength in CMPs and PCPs among athletes, and elucidate the unique characteristics of CMPs based on these correlations. The results revealed that the Vmean and Vmax of CMPs exhibited weaker correlations with maximal strength compared to those of PCPs, suggesting that non-strength factors may be more involved in influencing pull-up velocity in CMPs. This finding indicates that even in pull-up movements, which primarily involve upper-limb pulling actions, the utilization of countermovement may play a significant role. Accordingly, these findings offer valuable insights for evaluating novel training approaches incorporating countermovement into upper-limb pulling exercises, particularly among athletes.

A strong positive correlation was observed between the Vmean and Vmax of PCPs and LP-IMS. Although a significant weak correlation was found between the Vmean of CMPs and LP-IMS, no correlation was observed between the Vmax of CMPs and LP-IMS. These findings suggest that LP-IMS is less involved in determining Vmean and Vmax in CMPs than in PCPs. A previous study conducted under conditions similar to those of PCPs reported a very strong correlation between load (one-repetition maximum) and mean propulsive velocity.[14] However, in our study, isometric maximal strength was employed as the strength index, yet both the Vmean and Vmax of PCPs strongly correlated with LP-IMS. This consistency across different strength measures suggests that lifting velocity in PCPs is strongly dependent on maximal strength. By contrast, CMPs showed only a weak correlation between Vmean and maximal strength, and no significant correlation with Vmax, suggesting a weaker involvement of maximal strength in CMPs.

Related to these findings, previous studies on lower limb movements in countermovement jumps have shown that final jump velocity and jump height are not necessarily directly influenced by isometric mid-thigh maximal strength. Instead, factors such as SSC efficiency, explosive force production (rate of force development), and neuromuscular control play a more dominant role.[28,29] Furthermore, a study reported that ballistic movements utilizing the SSC are related to strength and power but are not entirely dependent on them, emphasizing the effectiveness of plyometric training.[30] Based on these considerations, utilizing the SSC through countermovement in pull-up motions may contribute to Vmean and Vmax as a non-strength-related factor. Supporting this finding, a previous study employing a vertical platform specifically designed for pull-ups emphasized the role of the reversal phase, reporting that strong muscle activation in the eccentric phase accumulates elastic energy. This energy is subsequently released during the concentric phase, thereby utilizing the SSC.[31] These findings suggest that SSC utilization plays a crucial role in determining the Vmean and Vmax in CMPs; however, the design of our study alone cannot establish a causal relationship between SSC utilization and Vmean or Vmax. Therefore, longitudinal studies incorporating training interventions are warranted to accurately evaluate the impact of strength on SSC capacity in pull-ups and clarify whether SSC utilization contributes to the mechanical variables of CMPs.

A strong negative correlation was observed between the time to Vmax of CMPs and LP-IMS, whereas a moderate but weaker negative correlation was identified between the time to Vmax of PCPs and LP-IMS (r_s = –0.319). Although CMPs tended to show a stronger association, the 95% CIs partially overlapped, rendering the evidence insufficient to definitively demonstrate a distinct difference. These results suggest that the time to Vmax of CMPs is more strongly associated with LP-IMS than that of PCPs. A previous study on pure concentric contractions reported that initial acceleration and starting velocity depend on the rate of force development at the beginning of the concentric phase.[32] Given that the LP-IMS measured in this study does not evaluate ballistic strength, this may elucidate why the time to Vmax of PCPs exhibited a weaker correlation with LP-IMS than the time to Vmax of CMPs. A study on lower-limb movements suggests that high force production at the conclusion of the eccentric phase contributes to the rate of force development,[33] indicating that strength during the transition phase affects subsequent movements. Furthermore, research on elbow flexion involving countermovement has also demonstrated a strong relationship between eccentric strength and initial force production.[34] Considering these findings, future studies should incorporate measurements of ballistic strength and eccentric-phase strength in addition to the maximal strength assessments used in this study to provide a more comprehensive understanding of the relationship between pulling movements and SSC utilization.

This study has certain limitations. First, maximal strength was measured using the lat pulldown exercise. Although a strong correlation exists between lat pulldown and pull-up performance, and LP-IMS was adopted due to its ability to control the influence of body weight and movement technique, the differences in movement patterns between the two exercises may have influenced the results. Second, despite strict evaluations conducted by two certified professionals, it cannot be entirely ruled out that some trials were not clearly distinguished. Therefore, future studies should consider using motion capture systems or video analysis to enhance assessment objectivity.

Despite these limitations, this study holds considerable significance as it analyzed the relationship between mechanical variables obtained using linear position transducers, which are widely applied in practice, and maximal strength in CMPs and PCPs. Notably, our findings suggest that the Vmean and Vmax of CMPs may be influenced by factors other than maximal strength. Previous studies have reported very strong correlations between maximal strength and the Vmean of PCPs, indicating that improvements in strength contribute to velocity gains in PCPs. By contrast, this study revealed that maximal strength does not substantially influence lifting velocity in CMPs, suggesting that factors other than strength are important for improving velocity. Indeed, SSC utilization has been confirmed in continuous pull-up movements, and although strength is strongly associated with velocity in PCPs, training for CMPs should consider the influence of SSC efficiency and other contributing factors.

This study was constrained by its cross-sectional design, which precludes the establishment of causal relationships between strength and performance in CMPs and PCPs, and did not directly examine the effects of CMPs as a training intervention. Therefore, caution is required when interpreting the findings. Future research should include longitudinal studies to identify non-strength-related factors influencing CMP mechanical variables and to further elucidate their practical applications. Additionally, incorporating analyses of ballistic characteristics and eccentric action strength may yield deeper insight into the role of countermovement in pulling tasks, thereby providing valuable knowledge for optimizing training methodologies in sports that demand efficient and powerful pulling actions.

In conclusion, this study examined the correlations between mechanical variables and maximal strength in CMPs and PCPs among athletes, and elucidated the unique characteristics of CMPs based on these relationships. The results showed that the correlations between Vmean and Vmax in CMPs and LP-IMS were weaker than those observed in PCPs, suggesting that factors other than maximal strength—such as SSC efficiency facilitated by countermovement—play a more prominent role in determining the Vmean and Vmax in CMPs. These findings indicate that the determinants of lifting velocity differ between CMPs and PCPs, revealing distinct mechanical characteristics between the two movements. Future studies should further investigate non–strength-related mechanisms by incorporating longitudinal designs, as well as evaluations of eccentric strength and rate of force development, to clarify the role of SSC efficiency. The present findings provide important implications for both the theoretical foundation and practical application of upper-limb SSC training in sports that require explosive pulling actions. In particular, the distinct relationship between maximal strength and performance in PCPs versus CMPs offers valuable insights for designing more effective training programs.

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