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ORIGINAL ARTICLE

Characteristics of countermovement pull-up: A comparison of mechanical variables between countermovement pull-up and pure concentric pull-up in athletes

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ABSTRACT

Recent research on pull-ups has introduced training methods using velocity-based approaches and the stretch-shortening cycle (SSC). However, the mechanical properties of countermovement pull-ups (CMP), which utilize SSC in upper-body movement only, remain underexplored. In this study, we compared CMP and pure concentric pull-ups (PCP) in trained collegiate athletes to examine the characteristics of the upward phase during CMP. This study included 36 collegiate athletes (swimmers and throwers) capable of performing at least ten consecutive pull-ups. Using a linear position transducer, peak velocity (Vmax), mean velocity (MV), mean power (MP), and time to peak velocity (Time to Vmax) were measured for both CMP and PCP, performed with upper-body movement only. The results showed that CMP had significantly higher MV (p < .05, d = 0.351) and shorter Time to Vmax (p < .01, r = 0.762) than PCP. These findings suggest that even without lower-limb involvement, CMP can enhance movement speed through SSC utilization and that countermovement can reduce Time to Vmax. The study findings contribute to understanding the role of SSC in upper-body training and offer practical insights for designing more effective pull-up training programs.
Keywords: Performance analysis, Plyometric, Upper limb, Stretch-shortening cycle, Velocity-based training, Power, Sports training.

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INTRODUCTION

Countermovement plays a key role in enhancing athletic performance (Takarada et al., 1997; Van Hooren and Zolotarjova, 2017). During this movement, elastic energy is stored in the muscle-tendon units through eccentric contractions while neural activation increases. Consequently, the subsequent concentric contraction is performed more efficiently and powerfully, leading to improved physical output. This sequence of muscular activity is known as the stretch-shortening cycle (SSC) (Komi, 2000). The SSC has been shown to enhance mechanical variables such as force, velocity, and power, thereby contributing to athletic performance (Komi, 2000; Takarada et al., 1997; Saunders, 2006). Accordingly, the application of countermovement to utilize the SSC is considered a fundamental strategy in both sports training and performance enhancement. However, most SSC-related studies have primarily focused on the lower limbs, while research on upper-limb applications remains limited (Davies et al., 2015; Garcia-Carrillo et al., 2023; Pérez-Castilla et al., 2020; Singla et al., 2018). Meanwhile, it has also been shown that upper-body strength and power are critical for success in many sports (Garcia-Carrillo et al., 2023; Singla et al., 2018).

Pull-ups are a fundamental exercise for developing pulling strength (Ronai et al., 2014), and their training effects have been investigated across various athletic populations (Franchini et al., 2011; Nikooie et al., 2017; Pérez-Olea et al., 2018). In recent years, the use of linear position transducers (LPTs) to measure movement velocity and power output during exercise has become widespread (Guerriero et al., 2018; Weakley et al., 2021). This methodology has also been validated for use in pull-up performance evaluation (Muñoz-López et al., 2017; Sánchez-Moreno et al., 2020).

Furthermore, recent studies have shown that the SSC is also utilized during pull-ups (Vigouroux et al., 2023), and increasing attention has been given to the application of countermovement in this context (Devise et al., 2023). In particular, studies involving climbers demonstrated that countermovement pull-ups (CMP) can induce the SSC, resulting in higher mean ascent velocity compared to purely concentric pull-ups (PCP), which do not involve countermovement (Devise et al., 2023). However, since the use of the lower limbs was permitted in these studies, the specific characteristics of CMP when restricted to upper-limb movements remain unclear. Moreover, further studies involving broader athletic populations are necessary to validate CMP's effectiveness as a training method. Given this background, a comparative analysis of mechanical variables such as velocity and time between CMP and PCP—which has already been the subject of ascent velocity studies (Muñoz-López et al., 2017)—may not only clarify the characteristics of SSC utilization in pull-ups but also provide valuable insights for developing new SSC-based training strategies. Such strategies, using widely available LPTs, would be particularly relevant for sports that require powerful pulling actions.

Therefore, the aim of this study was to compare the mechanical characteristics during the ascent phase of CMP and PCP in trained athletes to elucidate the specific features of countermovement-based pull-ups.

MATERIALS AND METHODS

Participants

Male collegiate athletes who had consistently performed pull-up training at least twice a week for over 1 year were recruited for this study. Inclusion criteria required that participants had no history of major upper-body injuries within the past year and were able to perform at least 10 consecutive pull-ups, as confirmed through verbal screening. Initially, 40 individuals expressed interest in participating. However, two were excluded due to injuries sustained during the testing period, and another two were unable to complete 10 consecutive pull-ups. Consequently, 36 participants were included in the final analysis. Participants were selected from a variety of sports disciplines, including swimming, javelin throw, discus throw, and hammer throw. No restrictions were placed on the type of sport, ensuring a diverse athletic sample.

The sample size exceeded the minimum requirement of 35 participants, which was determined through a priori power analysis. Therefore, the statistical power of the study was considered sufficient. Before the start of the study, all participants were provided with detailed verbal and written explanations regarding the research procedures and potential risks. Informed consent was obtained from the participants through signed consent forms. The study protocol was approved by the Human Research Ethics Committee of Tokai University (Approval No. 20148).

Procedures

A within-subject repeated measures design was employed in this study. All participants performed trials according to a standardized protocol. To eliminate the influence of competition schedules or excessive training, testing was conducted within 1 week following the end of each participant's competitive season. All trials were performed indoors at a university training facility on the same day, between 1:00 p.m. and 4:00 p.m.

Participants were instructed to refrain from high-intensity physical activity on the day before testing to ensure optimal performance. Before testing, each participant completed a 10-minute warm-up on a stationary cycle ergometer. This was followed by two familiarization repetitions for each trial condition, performed at approximately 50% of the perceived maximal effort.

Based on prior research (Devise et al., 2023), which tested strict pull-ups (similar to PCP, performed without countermovement) before CMP, the trial order in the present study was set as CMP followed by PCP. To minimize the effects of fatigue, a 3-minute rest interval was provided both after the warm-up and between each trial condition.

Measurements

Pull-up Protocol

A power rack (Hammer Strength, HD Elite Half-Rack, Illinois, USA; bar diameter: 3.5 cm) was used for all testing. The pull-up bar was set at a height of 2.50 m from the ground. Participants used a shoulder-width, overhand (pronated) grip during all trials.

PCP

To assess pull-ups without countermovement, participants performed PCP. While keeping their torso vertical, participants hung from the bar with their arms fully extended and held the position for 2 seconds following the tester's verbal cue. After this pause, they performed a single explosive upward movement as quickly as possible in the vertical direction. No specific instructions were provided for the descent phase; participants were allowed to return to the starting position naturally.

CMP

Figure 1 illustrates the CMP procedure used in this study. The starting position was defined as the top of the head aligned with the pull-up bar. To ensure consistency, a stick was set at bar height by the tester, and participants adjusted their position so that the top of their heads touched the stick. This setup was conducted while participants stood on the safety bar to minimize fatigue.

After positioning, participants lifted their feet off the safety bar and held a static position for 2 seconds upon the tester's count. They then rapidly dropped into full elbow extension in a relaxed manner, immediately followed by a powerful upward movement to perform the countermovement pull-up.

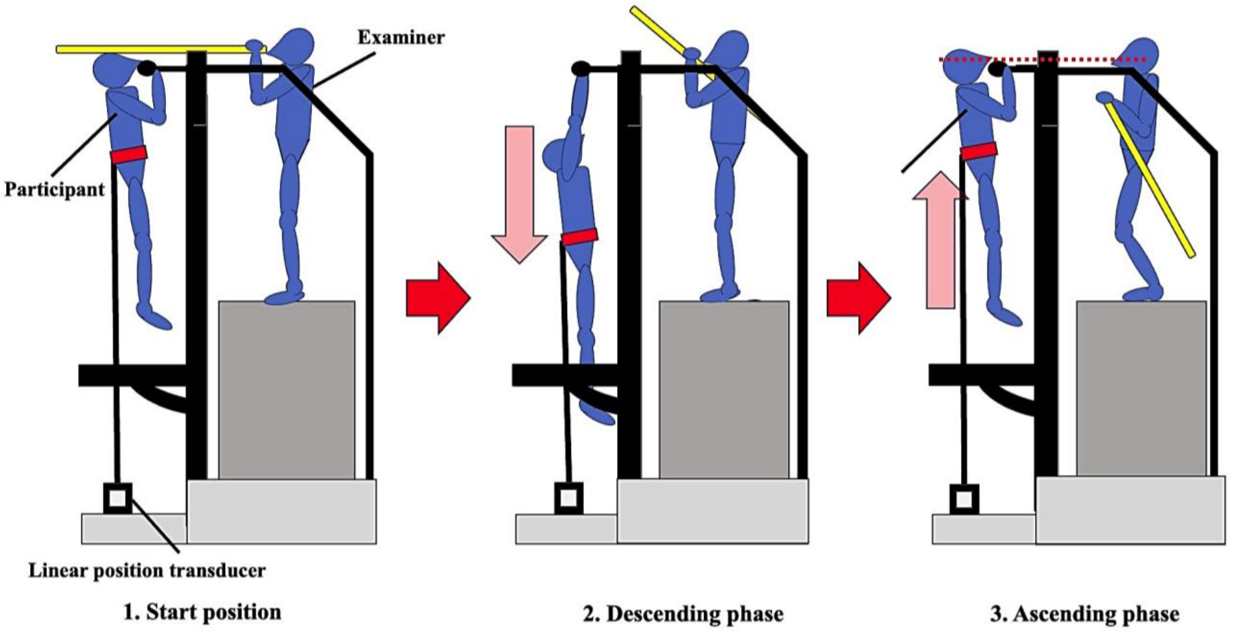

Figure 1. Countermovement pull-up procedure.

In both PCP and CMP conditions, participants were instructed to ensure their noses clearly passed above the bar and to minimize excessive forward or backward movement of the torso. To isolate upper-body performance, any use of the lower limbs or trunk for momentum (i.e., "*cheating*") was prohibited. Participants were required to maintain full extension at the knees and hips throughout each trial. Trials that failed to meet these criteria were considered invalid. Trial validity was determined based on predefined criteria and confirmed by agreement between two certified evaluators (CSCS, National Strength and Conditioning Association). When an invalid trial occurred, participants rested for 3 minutes before attempting a re-trial. These strict procedures were employed to ensure measurement reliability and reproducibility.

Mechanical variables and data acquisition

Mechanical variables—specifically movement velocity and duration—were measured using the Vitruve linear position transducer (LPT; SPEED4LIFTS S.L., Madrid, Spain), which has demonstrated high reliability in previous research (Kilgallon et al., 2022; Pérez-Castilla et al., 2019). Using the LPT, the following indicators were measured during both the eccentric (descent) and concentric (ascent) phases: peak velocity (Vmax), mean velocity (MV), mean power (MP), duration, and time to peak velocity (Time to Vmax).

Previous studies on pull-ups involving SSC utilization have identified a deceleration phase toward the end of the eccentric movement, characterized by increased muscular activity (Vigouroux et al., 2023). Therefore, in the present study, deceleration time was calculated as a supplementary variable to further explore the relationship between the eccentric and concentric phases. Deceleration time was defined using the following equation:

$$\text{Eccentric duration (s)} - \text{Eccentric Time to Vmax (s)} = \text{Deceleration Time (s)}$$

During measurement, the tip of the LPT wire was attached to a belt secured around the participant's fifth lumbar vertebra (L5). The LPT device itself was placed directly below L5, and the wire was carefully aligned to remain vertical before each trial. To ensure measurement accuracy, the device was calibrated and checked for functionality before each session. Special care was taken to prevent wire misalignment, which could compromise data integrity. Data were collected in real time using the Vitruve mobile application (version 4.29.1) via Bluetooth connection to a 7th-generation iPad tablet (Apple Inc., Cupertino, CA; iOS version 15.5). All data were sampled at 100 Hz and filtered prior to further processing.

Statistical analysis

The required sample size was estimated using G*Power software (version 3.1.9.7) [Faul et al., 2009; Kang, 2021]. The calculation was based on a medium effect size (Cohen's d = 0.5), a statistical power ($1 - \beta$) of 0.80, and a significance level (α) of .05. The results indicated that a sample size of 34 participants was required for paired t-tests and 35 participants for Wilcoxon signed-rank tests.

All statistical analyses were conducted using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was used to assess the normality of each variable. Descriptive statistics were expressed as mean ± standard deviation (SD) for normally distributed data, and as median [IQR] for non-normally distributed data. For comparisons between CMP and PCP, paired t-tests were used when the assumption of normality was met; otherwise, Wilcoxon signed-rank tests were applied. Furthermore, to examine the relationship between deceleration time during CMP and the mechanical variables during the ascent phase, Pearson's product-moment correlation coefficients were calculated, provided that normality assumptions were satisfied. The threshold for statistical significance was set at $p < .05$ for all tests.

RESULTS

The participants had a mean age of 21.2 ± 1.3 years, height of 174.9 ± 6.2 cm, and body mass of 80.9 ± 18.1 kg.

Table 1. Comparisons of mechanical variables between the countermovement and pure concentric pull-up using the paired t-test (n = 36).

	CMP	PCP	*p*	ES (Cohen's *d*)
MV (m/s)	0.70 ± 0.14	0.66 ± 0.18	.043*	.351
Vmax (m/s)	1.09 ± 0.24	1.09 ± 0.27	.988	.002
MP (W)	551.46 ± 128.09	516.36 ± 152.36	.058	.327

*Note. Values are presented as mean ± SD. ES = effect size (Cohen's d); *p < .05, **p < .01 (Paired t-test). CMP = countermovement pull-up; PCP = pure concentric pull-up; MV = mean velocity; Vmax = peak velocity; MP = mean power.*

Table 2. Comparisons of mechanical variables between the countermovement and pure concentric pull-up using the Wilcoxon signed-rank test (n = 36).

	CMP (median [IQR])		PCP (median [IQR])		*p*	ES (*r*)
Duration (s)	0.61	[0.56 - 0.71]	0.81	[0.69 - 0.89]	<.001††	0,736
Time to Vmax (s)	0.22	[0.13 - 0.34]	0.42	[0.24 - 0.58]	<.001††	0,762

Note. Values are presented as median [IQR]. IQR = Interquartile Range; ES = effect size (r); †p < .05, ††p < .01 (Wilcoxon signed-rank test). CMP = countermovent pull-up; PCP = pure concentric pull-up; Time to Vmax = time to peak velocity.

Results from the paired t-test (Table 1) revealed that the MV during CMP was significantly higher than that during PCP ($p < .05$, $d = 0.351$). In contrast, no significant differences were observed in Vmax or MP between the two conditions. The Wilcoxon signed-rank test (Table 2) indicated that the Time to Vmax was significantly shorter in CMP than in PCP (p < .01, r = .762). Additionally, Pearson's correlation analysis showed a significant positive correlation between deceleration time and Time to Vmax (r = .512, p < .05), suggesting a potential relationship between eccentric control and concentric performance timing.

DISCUSSION

This study aimed to investigate the characteristics of CMP by comparing mechanical variables during the ascent phase between CMP and PCP in trained athletes. The results revealed that the MV during CMP was significantly higher than that during PCP, suggesting that countermovement may enhance ascent velocity even when the movement is restricted to the upper limbs. Additionally, the Time to Vmax was significantly shorter in CMP than in PCP, indicating that countermovement may contribute to more rapid acceleration during the initial phase of the ascent.

The shorter Time to Vmax observed in CMP suggests that countermovement facilitates earlier attainment of peak velocity. One well-documented benefit of the SSC is that eccentric loading enhances muscle tension before the concentric phase, thereby improving subsequent performance (Bosco et al., 1982). In CMP, the eccentric phase allows sufficient time for the muscles to pre-activate and generate force before transitioning to the ascent phase. In contrast, PCP requires force generation from a static position. Previous studies have demonstrated that the pre-activation of muscles during the late eccentric phase can enhance force production immediately upon the initiation of concentric movement (Bobbert and Casius, 2005; Bosco et al., 1982).

Research on countermovement jumps has similarly shown that the use of countermovement allows muscles to reach a high activation level before shortening begins, thereby avoiding the initial delay in force production typically observed in movements starting from rest (Bobbert et al., 1996; Van Hooren and Zolotarjova, 2017). Based on this observation, it is plausible that pre-activation during the deceleration phase of CMP contributes to rapid acceleration immediately after the transition to the concentric phase, thereby shortening the Time to Vmax.

However, this study did not include electromyographic (EMG) measurements; therefore, direct evidence of pre-activation cannot be provided. Nonetheless, in studies where EMG was used to analyse SSC in pull-ups, pre-activation was observed just before the concentric phase during the deceleration portion of the descent. This pre-activation was shown to enhance performance during the subsequent ascent phase via SSC utilization (Vigouroux et al., 2022). Taken together, the abrupt deceleration during the eccentric phase in CMP might have elicited pre-activation and increased SSC engagement, resulting in a shorter Time to Vmax compared to PCP. To further explore this possibility, a supplementary correlation analysis between deceleration time and mechanical variables was performed during the ascent phase.

The results revealed a significant positive correlation between deceleration time and Time to Vmax, suggesting that the deceleration phase may play a critical role in initiating rapid concentric movement. Similar findings have been reported in lower-limb movements, where intense muscle activity at the end of the eccentric phase contributes to greater early force output via SSC mechanisms (Bobbert and Casius, 2005; Bosco et al., 1982). To more clearly define whether a similar mechanism operates in CMP, future studies should incorporate EMG analysis and assess additional kinetic variables, such as the rate of force development (RFD) based on ground reaction force data. These approaches would help elucidate the neuromuscular characteristics and performance advantages of CMP more comprehensively.

The significantly higher MV observed in CMP compared to PCP suggests that the use of countermovement may enhance movement speed even when the motion is restricted to the upper limbs. Previous research on CMP reported increased ascent velocity attributed to both SSC utilization and coordinated lower-limb involvement (Devise et al., 2023). However, the present study restricted lower-limb movement, indicating that SSC activation within the upper limbs alone may have contributed to the enhanced MV. That said, the effect size for the difference in MV between CMP and PCP was relatively small, suggesting that the observed effect may be modest. This could be attributed to anatomical and functional differences between the upper and lower limbs. While the lower limbs are structurally optimized for power generation and efficient movement, the upper limbs are primarily adapted for fine motor control. As a result, the SSC effect may be more limited in the upper body, which may also explain why no significant differences were found in Vmax or MP between the conditions. Further research is needed to clarify which muscles and joints are primarily involved in SSC during CMP and how these neuromuscular mechanisms are activated. Such work would advance our understanding of SSC dynamics in the upper body.

This study has some limitations. First, all participants performed the trials in a fixed order—PCP followed by CMP—based on previous research protocols. Therefore, it cannot be ruled out that the order of execution may have influenced the results. Future studies employing randomized experimental designs are recommended to more precisely evaluate the effects of CMP. Second, the participant sample was limited to male collegiate athletes who regularly trained at least twice per week and could perform a minimum of 10 consecutive pull-ups. Thus, the generalizability of the findings to other populations—such as different age groups, female athletes, or individuals with varying sports backgrounds—remains uncertain. Nonetheless, by not restricting participants to a specific sport, a degree of generalizability is maintained, although further research involving diverse populations is warranted.

Despite these limitations, the primary aim of this study was to identify the mechanical characteristics of CMP and to contribute to the development of optimized training approaches for upper-body-dominant sports. The use of practical mechanical variables allowed us to examine CMP in a manner that directly applies to real-world training settings. In this regard, the present findings provide valuable insights into the implementation of SSC-based training using CMP for athletic performance enhancement. Moving forward, a more comprehensive investigation combining three-dimensional motion capture, EMG, and kinetic analysis is needed to better understand the specific neuromuscular characteristics of CMP. Clarifying these mechanisms will deepen our theoretical and practical understanding of SSC utilization in the upper body and support the development of evidence-based training strategies for athletes.

CONCLUSIONS

This study compared the mechanical characteristics of CMP and PCP in collegiate athletes, with a focus on identifying how countermovement influences performance during the ascent phase. The findings suggest that CMP may reduce the time required to reach peak velocity and that the SSC may enhance MV even when the movement is restricted to upper-limb actions. These results contribute to a deeper understanding of SSC utilization in pull-ups and offer valuable insights for designing upper-body training programs that incorporate countermovement to optimize performance.

AUTHOR CONTRIBUTIONS

The study was conceptualized by K.H., J.Y., and S.A. Data curation was performed by S.A. Formal analysis, investigation, methodology development, validation, and visualization were conducted by K.H. Project administration and resource management were handled by S.A. Supervision was provided by J.Y. and S.A. The original draft of the manuscript was written by K.H., and the manuscript was reviewed and edited by J.Y. and S.A. All authors have read and approved the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

DATA AVAILABILITY

Available on request.

CONSENT TO PARTICIPATE

All participants signed an informed consent form prior to participating in this study.

CONSENT TO PUBLICATION

All participants signed an informed consent form giving permission for the publication of data collected.

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