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Phase specific changes in the countermovement jump occur without change in peak metrics following training

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ABSTRACT

The countermovement jump (CMJ) is routinely used to assess changes in strength-power qualities. Common measures derived from this test include jump height, peak power and peak velocity. However, valuable information on training induced changes in CMJ performance may be missed if phase and subphase variables are not included in the analysis also. The objective of this investigation was to determine whether significant performance changes can occur in the CMJ in the absence of changes in jump height or peak-form metrics. Sixteen recreationally trained males undertook 10-weeks of resistance training consisting of weightlifting, ballistic and plyometric actions with heavy and light loads. The CMJ was performed pre- and post-test with both peak-form metrics and mean phase/subphase metrics analysed. Mean velocity ($p < 0.01$) and mean power ($p < 0.01$) significantly improved following training while peak velocity ($p = 0.18$), peak power ($p = 0.29$), and jump height ($p = 0.24$) did not. Work, countermovement depth, eccentric duration and total movement duration significantly improved too ($p < 0.01$ to 0.03). Practitioners should consider using CMJ variables beyond jump height and instantaneous metrics to more thoroughly diagnose performance changes of the leg extensors following training.

1. Introduction

The countermovement jump (CMJ) is routinely used to assess changes in strength-power qualities in response to training (Cormie, McBride, & McCaulley, 2009; Harrison, James, McGuigan, Jenkins, & Kelly, 2019; McMahon, Suchomel, Lake, & Comfort, 2018). Although a multitude of measures can be derived from this test, arguably the most common are jump height, peak power and peak velocity. Peak measures are the highest value across a single sample and are therefore dictated by the sampling frequency of the instrumentation (e.g., 1000 Hz = 0.001s). CMJ velocity, power and force can also be averaged over phases of interest, like the concentric phase (~0.1 to 0.3s). These mean-form variables provide greater insight into changes throughout the CMJ than isolated measures because they enable researchers and practitioners to consider longer periods of phases of interest rather than a single data point (e.g., 0.001s) (Lake, Mundy, Comfort, & Suchomel, 2018). Furthermore, explosive athletic actions occur over more similar epochs to that of mean-form metrics suggesting that these variables are of greater relevance to sports performance, particularly from a temporal perspective (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Tidow, 1990). A focus on peak metrics alone might therefore cause the analyst to miss key underlying performance changes and draw erroneous conclusions about the state of the training process.

While light ballistic and heavy strength training modalities have resulted in considerable increases in peak CMJ measures (e.g., peak velocity), improvements in the equivalent mean variables (e.g., mean velocity) are more modest (Cormie, McGuigan, & Newton, 2010b, 2010c). One possible explanation for this is that previous investigations included only a single exercise modality and narrow loading conditions which consequently limited adaptations throughout the entire range of motion, resulting in attenuated improvements in phase/sub-phase metrics. This is a notable limitation as training plans in a sporting

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setting are typically mixed modality (Ebben, Carroll, & Simenz, 2004; Ebben, Hintz, & Simenz, 2005; Simenz, Dugan, & Ebben, 2005). In other words, they consist of a range of loading conditions and multiple forms of resistance training tasks such as ballistic, plyometric and heavy strength training.

The primary purpose of this investigation was to determine if a mixed modality resistance training intervention would elicit significant changes in CMJ phases and subphases without increases in common peak-form metrics (including jump height).

2. Methods

2.1. Participants and Training Intervention

Sixteen recreationally trained males (age: 25.5 ± 4.2 years; height 1.77 ± 0.08 m; body mass [BM]: 79.4 ± 11.2 kg; 1 repetition maximum squat: 1.60 ± 0.45 kg·kg·BM-1) undertook 10 weeks of resistance training, three days per week, consisting of weightlifting, ballistic and plyometric modalities under a spectrum of loads. Training has been described in detail previously (James et al., 2018) and is presented in Table 1.

2.2. Countermovement Jump Assessment

The CMJ test was performed on a force platform (Bertec Corporation, Columbus, OH, USA, sampling at 2000 Hz) at baseline and post-test using documented procedures (James et al., 2018). All CMJ force-time data were processed in a customisable spreadsheet. Briefly, force-time data were averaged over the first 1s of quiet standing to calculate subject weight. Additionally, the standard deviation of this period was quantified and the jump start threshold was determined by multiplying this by five and either subtracting this from or adding it to the subject's weight (depending on whether the maximum quiet standing force-time value was less or more than weight ± 5 SD). This weight was then subtracted from the force-time data to provide net force, which was then divided by body mass (weight ÷ the acceleration of gravity [a, 9.81 m/s/s]) to yield the acceleration of the centre of mass. A backward search was then performed from the 'jump start' to identify the last force-time intersection matching the weight (calculated on a trial-by-trial basis) and acceleration-time data were integrated from this point using the trapezoid rule to yield the velocity of the centre of mass. Power was then calculated by multiplying force by velocity on a sample-by-sample basis. Peak and mean velocity and power were calculated as the highest instantaneous value from the propulsion phase and as the value averaged over the propulsion phase respectively. Work was calculated by multiplying mean propulsion power by time. The eccentric phase was identified as beginning at the lowest countermovement velocity, ending at the transition from negative to positive velocity (lowest countermovement displacement); this marked the beginning of the propulsion phase, which ended at take-off. Countermovement depth was calculated as the change in centre of mass position from the jump start to the beginning of the propulsion phase, while eccentric duration was calculated as time from the lowest countermovement velocity until the start of the propulsion phase.

Table 1: Training intervention for this investigation. Loading for the weightlifting derivatives was taken from the power clean one-repetition maximum. Jump squat loading was taken from the one-repetition maximum back squat. Both these lifts were reassessed at mid-testing. All participants were familiar with the training and testing procedures. Where a range is given for loading, the lighter load was performed on day 1 and the heavier load on day 3. The depth jump volume progressed from three sets of three in week six to five sets of four in week 10.

Baseline-testing week								
	Day 1 and 3				Day 2			
Training Weeks 1-5	Exercise	Sets	Reps	Loading	Exercise	Sets	Reps	Loading
	Power clean	5	5	70%	Hang power clean	4	5	55%
	Jump squat	5	5	40-50%	Snatch pull	4	5	70%
Mid-testing week								
Training Weeks 6-10	Exercise	Sets	Reps	Loading	Exercise	Sets	Reps	Loading
	Jump squat	5	5	0-30%	Hang power clean	5	4	70%
	Power clean	5	4	85%	Snatch pull	5	4	85%
	Depth jump	3-5	3-4		Plyometric rebound split squat	4	3 each	
Recovery week								
Post-testing								

Table 2: Mean (SD) changes in countermovement jump variables following training. *d* = Cohen's *d* effect size.

	Pre		Post		*P*	*d*
Peak Power (W)	3780	(725)	3883	(564)	0.29	0.16
Mean Power (W)	1853	(369)	2006	(316)	<0.001	0.44
Peak Velocity ($m \cdot s^{-1}$)	2.65	(0.30)	2.72	(0.19)	0.18	0.28
Mean Velocity ($m \cdot s^{-1}$)	1.43	(0.19)	1.53	(0.13)	<0.001	0.58
Work (J)	600.67	(98.32)	644.20	(89.53)	<0.001	0.46
Countermovement Depth (m)	0.47	(0.05)	0.49	(0.04)	0.03	0.59
Eccentric Time (s)	0.31	(0.09)	0.23	(0.04)	<0.001	-1.02
Total Time (s)	1.12	(0.20)	0.98	(0.14)	0.01	-0.76

We then calculated and identified the middle 50% of 'initial flight' and referred to this as 'flight'. The mean (SD) 'flight' phase force was calculated, SD multiplied by 5 and this was added to the mean 'flight' force to identify take-off (first force <mean + 5 SD 'flight' force). Jump height was calculated from take-off velocity (take-off velocity2 ÷ 2a) and total movement duration was calculated as the period between the start and take-off.

2.3. Statistical Approach

Following confirmation of normality a paired samples t-test was used to determine whether there was a significant change in outcome variables following training (SPSS, Version 23.0, IBM Corporation, Somers, New York, USA). Cohen's *d* effect sizes were also calculated (Microsoft Excel 2013, Microsoft Corporation, Washington, USA).

3. Results

Significant increases in mean velocity and mean power were revealed following training in the absence of significant changes in peak velocity, peak power (Figure 1), and jump height. Work, countermovement depth, eccentric duration and total movement duration all changed significantly (Table 2). No change in BM occurred at post-test ($p = 0.35$).

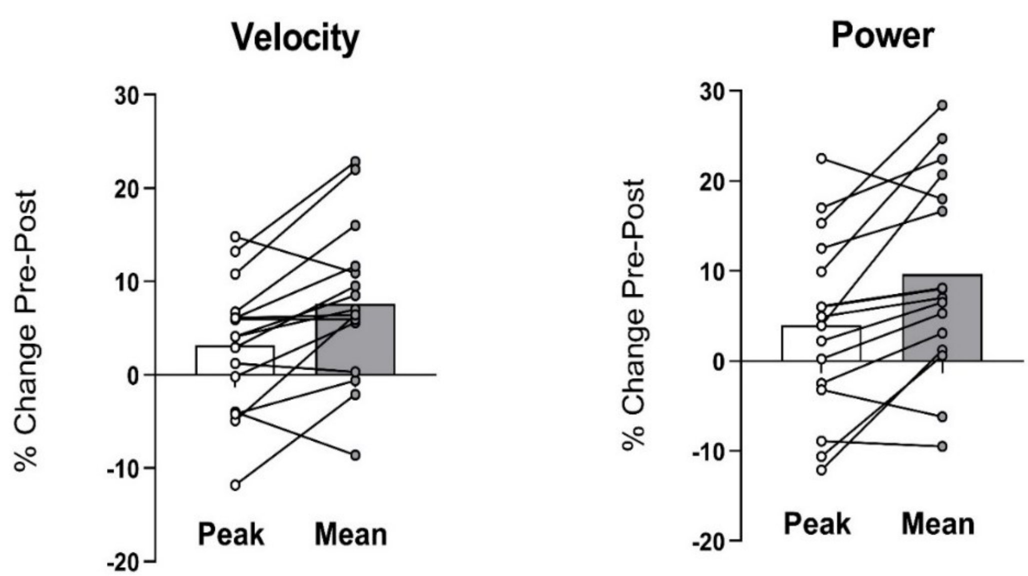

Figure 1: Individual changes in countermovement jump peak and mean velocity in addition to peak and mean power following strength-power training.

4. Discussion

The primary objective of this study was to determine whether changes in CMJ phase/subphase measures would occur in the absence of changes to peak metrics (e.g., peak power, jump height) following an ecologically valid resistance training intervention. These findings revealed statistically significant changes in several CMJ measures despite no alterations in peak velocity, peak power and jump height. These results show is that when analysing CMJ performance in a training environment it is important to consider all relevant variables to properly understand performance changes of the leg extensors. For example, if only peak velocity, peak power and jump height were analysed, as is often the case, an erroneous conclusion would have been drawn from these results because it could have suggested that the intervention did not effectively improve explosive leg muscle function. However, by including variables that enable study of CMJ jump strategy (mean velocity and power, work, and phase and sub-phase durations) we can see that this training strategy had positive and meaningful effect.

The intervention enabled subjects to increase their countermovement depth by an additional 2 cm. This has the potential to increase the stretch shortening cycle stimulus, particularly when combined with the fact that eccentric braking duration decreased significantly (Cormie, McGuigan, & Newton, 2010a). Because body mass remained consistent pre and post training this enabled subjects to perform significantly more work in less time during the countermovement and, accordingly, this improved post countermovement performance by facilitating movement velocity throughout the action. The additional countermovement displacement also caused more work to be performed during the propulsion phase (greater range of motion from the lowest squat position to take-off), and because this the action was performed significantly faster. As more work was performed at a faster rate, propulsion mean power was also significantly greater.

The present findings contrast with reports of greater increases in peak, with respect to mean, CMJ metrics following strength-power training. For example, Cormie et al. (2010b) found improvements of 10.0% and 9.6% in peak and mean power respectively in strong individuals following a jump squat only training intervention, with similar results occurring in weaker individuals also. In alignment with this, a heavy back squat only training plan elicited improvements of 10.9% and 7.6% in peak and mean power (Cormie et al., 2010b) respectively. When considered alongside these present findings, this may suggest that some diversity in movement pattern and loading is needed if improvements in whole-phase CMJ measures are of priority. In support of this notion, a previous investigation (Potteiger et al., 1999) incorporating a variety of plyometric exercises (vertical jumping, bounding and depth jumps) resulted in improvements in mean power (5.5%) approximately twice that of peak power (2.8%). However, as none of these investigations compared multi-versus single modality resistance training, it is challenging to draw definitive conclusions. A possible explanation for these findings is the variation in the rate and magnitude of loading throughout the triple (hip, knee and ankle) extension in training enabled transfer to greater regions of the CMJ force-time curve (Suchomel, Comfort, & Lake, 2017; Suchomel, Comfort, & Stone, 2015). Multiple lifts in the present training intervention have differing regions of accentuated force application throughout the course of the movement at a given load (Figure 2), which is a key factor in training transfer (Suarez, Wagle, Cunanan, Sausaman, & Stone, 2019). For example, the jump squat commences with an unweighting period with its peak force occurring somewhat gradually at the completion of the lift, whereas the snatch grip pull commences with a steady acceleration before an unweighting and a rapid rise in force in the second half of the lift. A limitation of this single cohort study design was the inability to identify how CMJ phases are altered following mixed versus single modality resistance training. Future investigations are needed to better understand the nature of CMJ phase changes in response to different strength-power stimuli.

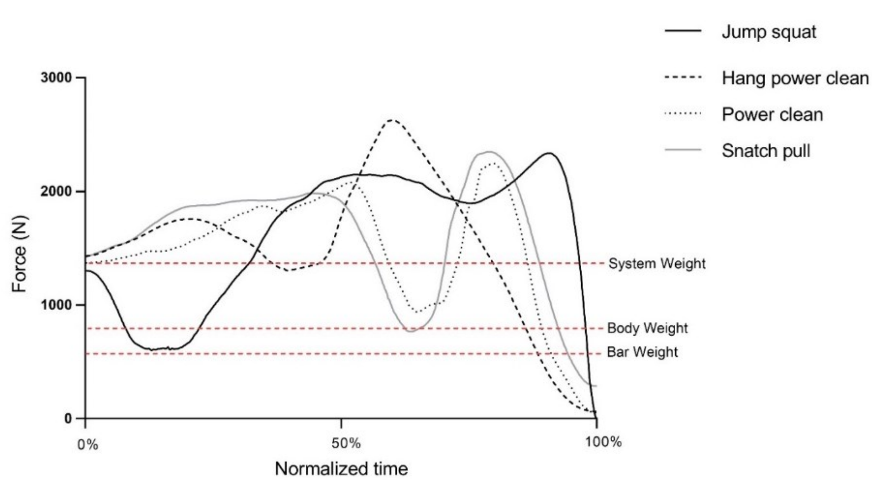

Figure 2: Case example of the normalised force-time curves of a subject across lifts included in the training intervention. All lifts in this figure were performed with the same bar mass.

These findings reinforce the need to focus on variables that consider performance over key phases and sub-phases. The focus on jump height or peak values of velocity and power may narrow the practitioner's or researcher's approach to CMJ force-time curve analysis by focusing on what amounts to a change in data that typically occurs in 1 ms (0.5 ms in this case, representing only 1.5% of mean propulsion duration).

Practical applications

- Where possible, practitioners should use CMJ variables beyond jump height and peak-form metrics.
- Phase/sub phase metrics provide critical insight into training induced adaptations that might otherwise be missed.

Conflict of Interest

The authors declare no conflict of interests.

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