

# Countermovement Jump Characteristics of World-Class Elite and Sub-Elite Male Sprinters

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## Headline

World-class 100m sprinters need a combination of exceptional acceleration, maximum-velocity and speed-endurance; each of which are dictated by their own complex interplay of physiological and biomechanical factors [1]. Previous research has highlighted the importance of lower-limb force production, and the direction of application, for elite sprint performance [2,3]. The countermovement jump (CMJ) is a popular explosive-strength assessment often utilised by coaches and sport scientists to ascertain an athlete's ability to rapidly apply vertical force with their lower limbs [4]. Compared to other strength diagnostic tests, the CMJ is highly practical due to its simplicity, low physiological strain, cost- and time-effective technology (i.e. smartphone app, contact mat, portable force platform). The CMJ can be used to monitor explosive-strength adaptation, direct gym programming and infer neuromuscular readiness of an athlete. In sprinters, previous research has found strong relationships between specific CMJ variables (i.e. jump height, peak power) and both acceleration ( $r = 0.52-0.86$ ) [5-9] and maximum-velocity performance ( $r = 0.55-0.77$ ) [10,11]. Consequently, depending on other confounding factors (i.e. sprint technique, anthropometrics, level of performance), it may be suggested that 30-75% of sprint performance variance is explained by explosive-strength [5-11]. However, previous research has mainly focused on sub-elite populations (100m personal best [PB] > 10.28s) [5,6,12,13] and there is a lack of literature investigating the CMJ characteristics of world-class elite male sprinters (100m PB < 10.15s).

## Aim

The aim of this study was to compare the CMJ phase characteristics (i.e. braking & propulsion phase variables) of world-class elite (100m PB: 9.96-10.14 s) and sub-elite (100m PB: 10.34-10.65 s) male sprinters. It is hypothesised that world-class elite male sprinters will demonstrate larger braking and propulsion phases variables (e.g. impulse, velocity), and therefore jump height, than sub-elite male sprinters.

## Methods

### Athletes

Eight world-class elite and sub-elite male sprinters volunteered to participate in this study (age  $21.5 \pm 2.9$  y, body mass  $77.8 \pm 6.0$  kg, height  $1.80 \pm 0.10$  m). Ethics approval was granted by the institute's ethics board and the study was conducted in accordance with the Helsinki Declaration. Informed consent was acquired from all subjects. At the time of testing, all participants had at least two years of training in competitive sprinting. The world-class elite group ( $n = 4$ ) competed at an international level and included a IAAF Diamond League 100m champion, a IAAF World Championship 100m finalist,

a European Athletics Under 23 100m champion, and a 100m Olympian. The sub-elite group ( $n = 4$ ) competed at a national level (see Table 1).

## Design

The cross-sectional study was conducted on a Monday morning (10:00-12:30) during the recovery week at the end of the participant's general preparation phase (GPP). All the participants had regularly performed CMJ testing throughout the GPP and were familiar with the testing protocol. Prior to the CMJ assessment, all participants performed a standardised warm-up consisting of mobility and sprint drills on the track (2 x 30m: A-skip, B-skip, backwards walk, side-walk, cross-over walk, carioca walk, ankle-dribble, calf-dribble, knee-dribble, straight-leg scissor, bent-leg scissor, fast-foot A, fast-foot B). Following the warm-up each participant completed 4 x 30m sub-maximal accelerations.

## Methodology

All CMJs were recorded at 500 Hz [14] using a dual PASPORT type PS-2141 force platform (PASCO scientific, Roseville, CA, USA). Prior to the CMJs, participants were instructed to stand still for the initial 1s of data collection for determination of body weight (vertical force averaged over 1s) [15,16]. To restrict arm swing throughout the CMJ, each participant was instructed to keep their hands on their hips throughout the jump [15,16]. The downward phase (i.e. the countermovement) of each jump was performed to a self-selected depth. When ready, participants were instructed to "jump as high as possible." Each participant performed three maximal trials, with each jump separated by 10s of recovery.

All raw vertical force-time data was instantaneously analysed using ForceDecks software (NMP ForceDecks Ltd., UK). The onset of movement (ON) was defined as the point when the total vertical ground reaction force (vGRF) deviated -20 N from body weight, and the take-off (TO) was set to the point when the total vGRF dropped below 10 N. Jump height was calculated using the impulse-momentum method with the total vGRF and its first derivative used to determine centre of mass (COM) vertical velocity [jump height =  $\frac{1}{2} * (\text{TO velocity}^2 / 9.81)$ ]. Contraction time quantified the entire movement time from ON to TO. Reactive-strength index modified (RSI-

**Table 1. Performance level, age and anthropometry of world-class elite and sub-elite male sprint groups. Mean  $\pm$  SD (range).**

	World-Class Elite (n = 4)	Sub-Elite (n = 4)
100m PB (s)	10.06 $\pm$ 0.08 (9.96-10.14)	10.53 $\pm$ 0.15 (10.34-10.65)
60m PB (s)	6.59 $\pm$ 0.06 (6.53-6.66)	6.87 $\pm$ 0.07 (6.78-6.95)
Age (y)	22.0 $\pm$ 2.83	21.0 $\pm$ 3.37
Height (m)	1.81 $\pm$ 0.08	1.75 $\pm$ 0.05
Body mass (kg)	76.25 $\pm$ 5.24	78.65 $\pm$ 6.23

**Table 2. World-class elite and sub-elite male sprinter comparisons for countermovement jump (CMJ) phase variables. Mean  $\pm$  SD (range).**

	World-Class Elite (n = 4)	Sub-Elite (n = 4)	p	g	Magnitude	CV%
<b>Performance</b>						
100m PB (s)	10.06 $\pm$ 0.08 (9.96-10.14)	10.53 $\pm$ 0.15 (10.34-10.65)	0.02	3.38	Very large	
60m PB (s)	6.59 $\pm$ 0.06 (6.53-6.66)	6.87 $\pm$ 0.07 (6.78-6.95)	0.001	3.64	Very large	
<b>Countermovement Jump Variable</b>						
Jump Height (m)	0.57 $\pm$ 0.03	0.44 $\pm$ 0.01	0.003	4.45	Very large	3.5
Contraction Time (s)	0.69 $\pm$ 0.08	0.62 $\pm$ 0.01	0.218	0.95	Moderate	5.2
RSImod	0.83 $\pm$ 0.07	0.72 $\pm$ 0.02	0.017	2.06	Very large	6.7
Countermovement Duration (s)	0.45 $\pm$ 0.06	0.42 $\pm$ 0.02	0.413	0.54	Small	6.5
Countermovement Depth (m)	-0.40 $\pm$ 0.05	-0.27 $\pm$ 0.02	0.003	2.88	Very large	6.2
<b>Braking Phase</b>						
Braking Impulse (Ns/kg)	1.79 $\pm$ 0.14	1.29 $\pm$ 0.22	0.007	2.40	Very large	6.8
Braking Peak Velocity (m/s)	-1.79 $\pm$ 0.13	-1.29 $\pm$ 0.22	0.007	2.46	Very large	6.8
Braking Peak Power (W/kg)	33.36 $\pm$ 7.20	20.55 $\pm$ 5.14	0.025	1.78	Large	12.8
Braking Peak Force (N/kg)	30.77 $\pm$ 2.92	28.56 $\pm$ 3.00	0.336	0.65	Moderate	5.2
<b>Propulsion Phase</b>						
Propulsion Impulse 50ms (Ns/kg)	0.99 $\pm$ 0.11	0.99 $\pm$ 0.13	0.978	0.02	Trivial	5.2
Propulsion Impulse 100ms (Ns/kg)	1.86 $\pm$ 0.19	1.96 $\pm$ 0.20	0.512	0.44	Small	3.9
Propulsion Impulse (Ns/kg)	3.34 $\pm$ 0.09	2.95 $\pm$ 0.04	0.001	4.57	Very large	1.8
Propulsion Peak Velocity (m/s)	3.43 $\pm$ 0.09	3.05 $\pm$ 0.04	0.001	4.57	Very large	1.6
Propulsion Peak Power (W/kg)	75.00 $\pm$ 2.60	68.20 $\pm$ 3.15	0.016	2.05	Very large	2.1
Propulsion Peak Force (N/kg)	30.50 $\pm$ 2.53	30.51 $\pm$ 2.28	0.989	0.00	Trivial	3.1
Propulsion Duration (s)	0.23 $\pm$ 0.02	0.20 $\pm$ 0.01	0.028	1.79	Large	3.3

PB: personal best; CV%: between-trial coefficient of variation; g: Hedges' g effect size; p = p value.

mod) was calculated as jump height divided by contraction time. The unweighting phase from ON to the instant of maximum negative velocity corresponding to when body weight was re-established in the total vGRF force.

The braking phase (also known as the 'eccentric deceleration' phase) [15,16] was from the instant of maximum negative velocity of the COM corresponding to when body weight is re-established in the total vGRF force to when COM velocity was zero (i.e. when the participant stops momentarily at the bottom of the squat position). The braking phase impulse was determined as the net impulse from onset of deceleration to the end of braking phase. Braking peak velocity was defined as the maximum negative (downward) COM velocity. Braking peak power was the maximum power in the braking phase. Braking peak force was determined as the force at the end of the braking phase when velocity when zero. Countermovement duration was determined from the instant of ON to the end of the braking phase.

The propulsion phase (also known as the 'concentric' phase) [15,16] was from the instant where COM vertical velocity was zero to TO. Propulsion impulse 50ms was defined as the net impulse in a 50ms duration from the onset of the propulsion phase. Propulsion impulse 100ms was defined as the net impulse in a 100ms duration from the onset of the propulsion phase. Propulsion impulse was calculated as the net impulse in the propulsion phase from onset of the propulsion phase to the instant of TO. Propulsion peak velocity was defined as the COM peak velocity in the propulsion phase. Propulsion peak power was determined as the peak power in the propulsion phase. Propulsion peak force was calculated as the peak vGRF in the propulsion phase. Propulsion duration was defined as the time interval from the onset of propulsion phase to the instant of TO. All kinetic data were divided by body mass to allow for a normalised comparison between groups.

## Statistical Analysis

Results were expressed as mean  $\pm$  SD. The mean output of each variable during the three CMJ trials was taken forward for statistical analysis. All data satisfied parametric assumptions. Mean differences in each parametric variable derived from the world-class elite and sub-elite groups were compared using independent t-tests. Independent t-tests were performed using SPSS software (version 20; SPSS Inc, Chicago, IL, USA) with the alpha level set at  $p \leq .05$ . Mean between-trial variability of each variable was calculated using the coefficient of variation expressed as a percentage (CV%). Due to the small sample size, effect sizes were calculated using the hedges' g method to provide a measure of the magnitude of the differences in each variable between groups [17]. The effect sizes were then descriptively interpreted in line with previous recommendations [17].

## Results

Comparisons of world-class elite and sub-elite male sprint groups for CMJ phase variables are presented in Table 2.

## Discussion

The aim of this study was to compare the CMJ phase characteristics of world-class elite and sub-elite male sprinters. Previous research has found that CMJ height differentiates between performance level in sub-elite 100m sprinters [13]. However, to date, this is the first study to compare the CMJ phase characteristics (i.e. braking and propulsion phase variables) of world-class elite (100m PB: 9.96–10.14 s) and sub-elite sprinters (100m PB: 10.34–10.65 s). The main finding of this study was that, compared to sub-elite sprinters, world-class sprinters produce a significantly larger impulse, peak velocity and power in both braking and propulsion phases of the CMJ, resulting in a significantly greater jump height and RSImod. This nov-

elty provides new insight into the explosive-strength ability of world-class male sprinters.

During a CMJ, impulse can provide information on the total amount of force generated during specific phases of the movement (i.e. braking and propulsion phase) [15,16]. Impulse is the integration of force and time, and therefore determines the velocity of the athlete's COM to which the impulse is applied [18,19]. During the unweighting phase of the jump (the phase where the countermovement is initiated through the relaxation of agonist leg musculature), the world-class elite sprinters produced a significantly larger relative impulse compared to the sub-elite group. Therefore, the effect of the larger unweighting impulse in the elite group led to a significantly faster peak [negative] velocity at the start of the braking phase (also known as the 'eccentric deceleration' phase) of the jump ( $-1.79 \pm 0.13$  vs.  $-1.29 \pm 0.22$  m/s) [15,16]. The faster velocity of the COM influences the rate and magnitude of force that must be produced during the braking phase to reduce momentum to zero. Consequently, the elite sprinters produced a significantly larger braking impulse compared to the sub-elite group ( $1.79 \pm 0.14$  vs.  $1.29 \pm 0.22$  Ns/kg). Additionally, braking peak power was also significantly greater for the elite sprinters ( $33.36 \pm 7.20$  vs.  $20.55 \pm 5.14$  W/kg). However, it is important to note that the elite sprinters had a significantly greater countermovement displacement when compared to the sub-elite group ( $-0.40 \pm 0.05$  vs.  $-0.27 \pm 0.02$  m). This larger countermovement depth in the elite group may have been an intuitive jump strategy to create a longer duration to produce force and increase both braking and propulsion impulse, and therefore jump height (see Table 2).

During the propulsion phase (also known as the 'concentric' phase), the world-class elite group produced a significantly larger relative impulse compared to the sub-elite group ( $3.34 \pm 0.09$  vs.  $2.95 \pm 0.04$  Ns/kg). This larger concentric impulse enabled the elite sprinters to achieve a greater take-off velocity and subsequently higher jump height ( $0.57 \pm 0.03$  vs.  $0.44 \pm 0.01$  m) [15,16]. Interestingly, this larger impulse was achieved by the elite sprinters despite the group demonstrating similar propulsion peak force to the sub-elite sprinters (see Table 2). The main mechanism behind the larger propulsion impulse in the elite group may have been due to a superior utilisation of their stretch-shortening cycle (SSC) (i.e. series elastic component and stretch-reflex mechanisms). The RSI-mod variable provides more insight into SSC function than jump height alone [20-22]. RSI-mod accounts for the total duration of force production (i.e. contraction time) throughout the movement to achieve the given jump height ( $\text{RSI-mod} = \text{jump height} \div \text{contraction time}$ ) [20]. In this study, the elite group produced a significantly larger RSI-mod than the sub-elite group ( $0.83 \pm 0.07$  vs.  $0.72 \pm 0.02$ ), therefore potentially demonstrating a more efficient SSC [22]. Early work in muscle-tendon physiology suggested that the extent of concentric performance during a SSC movement is largely derived by the conditions of the previous eccentric contraction (i.e. rate and magnitude of stretch during the braking phase) [23]. Therefore, the elite group's larger RSI-mod may have been due to their superior eccentric characteristics (i.e. braking impulse, peak velocity), potentially augmenting the subsequent concentric impulse, take-off velocity and jump height.

Previous work from Cormie et al. [24] suggested that the SSC enhances force production early in the propulsion phase of a CMJ. However, in this study, the world-class elite and sub-elite sprinters produced a similar impulse over 50 and 100ms of the propulsion phase. This lack of increased force production early in the concentric contraction may be due to the elite group starting their propulsion phase at a lower countermovement depth and potentially a mechanically disadvantaged po-

sition (i.e. the length-tension relationship). Nonetheless, as mentioned previously, the lower countermovement depth may have been an intuitive strategy to increase propulsion contraction duration, impulse and therefore take-off velocity – but, this may be a trade-off at the expense of early propulsion phase force production. However, previous findings on countermovement depth and CMJ performance are conflicting. For example, Cormie et al. [25] found that countermovement depth did not distinguish between two groups of athletes who had similar CMJ performances to this study (CMJ height:  $0.58 \pm 0.05$  vs  $0.43 \pm 0.04$  m).

The main finding of this study was that, compared to sub-elite sprinters, elite world-class male sprinters produce a significantly larger impulse, peak velocity and power in both the braking and propulsion phases of the CMJ, resulting in a significantly greater jump height and RSI-mod. Although the physiological mechanisms underlying CMJ performance were not measured in this study, it is theorised that the world-class sprinter's explosive-strength ability is a result of their superior morphological (i.e. muscle fibre type, architecture, tendon properties) and neural characteristics (i.e. motor unit recruitment, synchronisation, firing frequency) [26]. These neuromuscular properties are most likely dictated by factors such as genetics and training background [27]. Future studies are needed in larger samples of elite sprinters to elucidate the sensitivity of CMJ phase variables (e.g. braking impulse, propulsion peak power, jump height and RSI-mod) in response to specific effects of training blocks, tapering and competition.

### Practical Applications

- Braking impulse, propulsion peak power, jump height and RSI-mod differentiates between performance level of world-class elite and sub-elite male sprinters. As well as meeting acceptable reliability criteria ( $CV < 7\%$ ), these four CMJ variables displayed the largest magnitudes between groups (Hedges'  $g = 2.05-4.45$ ).
- It is advised that coaches and sport scientists who have access to a force platform may consider monitoring and developing these CMJ variables throughout a sprinter's mesocycle (GPP → competition) alongside development of other strength qualities (e.g. special-strength, reactive-strength, maximal-strength) and sprint-specific training (e.g. acceleration, speed-endurance etc) [1].
- For coaches who do not have access to a force platform, and as jump height is almost perfectly related to relative propulsion impulse [18,19], it may be sufficient to monitor CMJ height alone utilising the flight-time method with other cost-effective technologies (i.e. phone applications, contact mats). However, it is imperative that the CMJ is executed correctly for accurate data collection using the flight-time method (i.e. the athlete's COM must be the same at CMJ take-off and touchdown, and therefore flexing of hips, knees & ankles prior to touchdown is not allowed).
- The underpinning determinants of CMJ performance are likely influenced by the pre-stretch of the muscle-tendon unit during the eccentric contraction (i.e. braking phase), of which this valuable information is only obtainable through force platform analysis. Please see evidence-based recommendations from Suchomel et al [28] for eccentric development in both elite and sub-elite athletes of varying strength levels.

### Limitations

- It is important to highlight that the main limitation of this study was the very small sample size and therefore caution

is needed when applying these findings. Future research is needed in larger samples of world-class sprinters.

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