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Young Investigator Section

Research article

JUMP KINETIC DETERMINANTS OF SPRINT ACCELERATION PERFORMANCE FROM STARTING BLOCKS IN MALE SPRINTERS

Peter S. Maulder [1]✉, **Elizabeth J. Bradshaw** [2] **and Justin Keogh** [1]

[1] Division of Sport and Recreation, Institute of Sport and Recreation Research New Zealand, Auckland University of Technology, Auckland, New Zealand.
[2] School of Exercise Science, Australian Catholic University, Melbourne, Australia

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ABSTRACT

The purpose of this research was to identify the jump kinetic determinants of sprint acceleration performance from a block start. Ten male (mean ± SD: age 20 ± 3 years; height 1.82 ± 0.06 m; weight 76.7 ± 7.9 kg; 100 m personal best: 10.87 + 0.36 s {10.37 - 11.42}) track sprinters at a national and regional competitive level performed 10 m sprints from a block start. Anthropometric dimensions along with squat jump (SJ), countermovement jump (CMJ), continuous straight legged jump (SLJ), single leg hop for distance, and single leg triple hop for distance measures of power were also tested. Stepwise multiple regression analysis identified CMJ average power (W/kg) as a predictor of 10 m sprint performance from a block start ($r = 0.79$, $r^2 = 0.63$, $p<0.01$, SEE = 0.04 (s), %SEE = 2.0). Pearson correlation analysis revealed CMJ force and power ($r = -0.70$ to -0.79; $p = 0.011 – 0.035$) and SJ power ($r = -0.72$ to -0.73; $p = 0.026 – 0.028$) generating capabilities to be strongly related to sprint performance. Further linear regression analysis predicted an increase in CMJ average and peak take-off power of 1 W/kg (3% & 1.5% respectively) to both result in a decrease of 0.01 s (0.5%) in 10 m sprint performance. Further, an increase in SJ average and peak take-off power of 1 W/kg (3.5% & 1.5% respectively) was predicted to result in a 0.01 s (0.5%) reduction in 10 m sprint time. The results of this study seem to suggest that the ability to generate power both elastically during a CMJ and concentrically during a SJ to be good indicators of predicting sprint performance over 10 m from a block start.

KEY WORDS: Anthropometry, horizontal jumps, sprint performance, vertical jumps.

INTRODUCTION

High performance sprint running from a block start requires the production of both high level forces and angular velocities (Harland and Steele, 1997; Mero et al., 1983; Mero et al., 1992). Specifically, large forces generated by the leg musculature whilst in the starting blocks can lead to a performance edge over the other competitors in the race (Harland and Steele, 1997). An explosive sprint start requires a powerful angular drive of the arms, hips and legs (Hoster and May, 1979; Korchemny, 1992). On and off-track resistance training, therefore, underpins the athletic program of the competitive sprinter (Delecluse et al., 1995). In the gymnasium the weighted squat jump (SJ), for example, is employed to increase the power of the hip and lower limb musculature. On the track, standard block start training is utilised to increase the athlete's hip drive, propulsive force generation whilst building a sound movement pattern to lead to superior start performance. Interestingly, the effect of these resisted training methods on sprint start performance (from blocks) is not well documented and therefore, the effects of jump training, strength training or standard block start training methods on the start and early acceleration phases are not well understood. This is perplexing as many methods are employed in the field without any empirical evidence to demonstrate their effectiveness for improving these phases of sprint running. Seemingly fundamental to the employment of these training tools is objective evidence that firstly, these specific tasks are related to superior sprint performance and, secondly, these methods are suitable for each individual athlete regardless of their current physical power and sprinting performance capabilities.

There is a paucity of published research into the relationship of strength and power measures with sprint performance using a block start. Abernethy and colleagues (1995) believed this to be reflective of the low priority given to publishing research of this nature by editors and researchers. However, such research is essential as it allows predictors of functional performance to be identified, which aid talent identification, programme development and may provide direction for mechanistic research. The majority of research studies that have examined the relationships between leg power and sprint ability have often used vertical or horizontal jump displacements as an indirect power measure with correlations ranging from r = 0.44 – 0.77 (Bret et al., 2002; Kukolj et al., 1999; Mero et al., 1983; Nesser et al., 1996). However, Bradshaw and Le Rossignol (2004) reported that the use of vertical height measures to gauge performance level in gymnasts was inadequate. In fact, of the few studies that have used more sensitive measures such as force and power developed during the jump task; all have reported stronger correlations with sprint performance. For example, very strong correlations of r = -0.88 and r = -0.86 have been reported between sprint performance and countermovement jump (CMJ) and weighted SJ jump kinetics respectively (Liebermann and Katz, 2003, Young et al., 1995). Whereas, low to moderate correlations ranging from r = 0.44 – 0.77 have been reported by other researchers between sprint performance and jump height ability from a CMJ and SJ (Bret et al., 2002; Kukolj et al., 1999; Mero et al., 1983). Therefore, identifying the predictive ability of more sensitive kinetic jump measures with sprint performance warrants further research. Understanding jump training methods will better assist training prescription for track coaches, conditioners and athletes alike.

The purpose of this research was to identify the jump kinetic determinants of sprint acceleration performance from a block start. It was hypothesised that athletes who produced large force and power outputs relative to bodyweight during jump activities will obtain high levels of sprinting performance. It is expected that this relationship will be greater in the horizontal than the vertical jumps due to the direction of force application and take-off angles.

METHODS

Participants

Ten male (mean ± SD: age 20 ± 3 years; height 1.82 ± 0.06 m; weight 76.7 ± 7.9 kg; 100 m personal best: 10.87 + 0.36 s {10.37 - 11.42}) track sprinters at a national and regional competitive level participated in the current study. Each participant gave written informed consent to participate in this study prior to testing. Ethics approval was obtained for all testing procedures from the Auckland University of Technology Ethics Committee.

Testing procedures

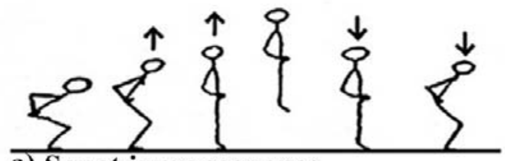
Sprint session

Testing was conducted at an IAAF accredited athletic stadium with a Mondo track surface. Each athlete completed their own individual warm-up under the supervision of their coach. The athletes were then asked to perform four 10 m sprints from a block start. The placement of the starting blocks was individually set according to the preference of each athlete. An experienced starter was used to provide standard starting commands to the athletes. The sprints were separated by a 3 minute rest period to ensure sufficient recovery. Athletes performed sprints in tight fitting clothing and track spike shoes. The two fastest trials for each condition were selected for the data analysis with the average time from these trials used as the outcome performance measure.

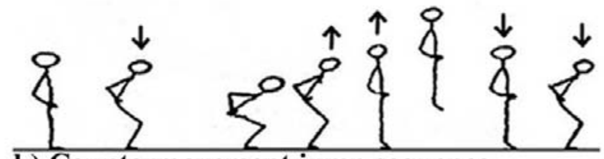
Jump session

Prior to jump data collection anthropometric testing was conducted by an International Society for the Advancement of Kinanthropometry (ISAK) level 2 anthropometrist. Physical dimensions of height, mass, shoulder (biacromial) width, hip (biiliocristal) width, femur (trochanterion-tibiale laterale) length, tibia to floor length (tibiale laterale), and tibia (tibiale mediale-sphyrion) length were measured. Upon completing the anthropometric assessment, each athlete completed their own individual warm-up under the supervision of their coach.

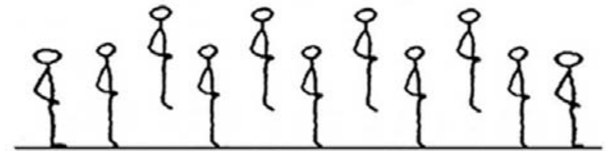
Five types of jump assessments were performed by each athlete; squat jump (SJ), countermovement jump (CMJ), continuous straight legged jumps (series of 5 jumps; SLJ), single leg hop for distance, and single leg triple hop for distance, all of which have been used extensively in the literature (Arteaga et al., 2000; Bradshaw and Le Rossignol, 2004; Kukolj et al., 1999; Markovic et al., 2004; Mero et al., 1983; Nesser et al., 1996; Ross et al., 2002; Young et al., 1995). All jump assessments were administered in a randomised order with three trials of each jump assessment being performed. All vertical jumps were performed bilaterally whereas the horizontal jumps were performed unilaterally with each leg being tested in a randomised order.



a) Squat jump sequence



b) Countermovement jump sequence



c) Continuous straight legged jump sequence

Figure 1. Vertical jump assessments performed

For the SJ the athlete started with their hands on their hips. They were then instructed to sink and hold a knee position (approximately 120° knee angle) for four seconds (see Figure 1a). On the count of four the athlete was instructed to then jump as high as possible. A successful trial was one where there was no sinking or countermovement prior to the execution of the jump.

The CMJ assessment required the athlete to start with their hands on their hips. They were then instructed to sink as quickly as possible and then jump as high as possible in the ensuing concentric phase (see Figure 1b).

The SLJ involved a series of approximately five jumps with straight knees using the ankles to jump (see Figure 1c). Athletes were permitted to hold their arms loosely by their side during the SLJ test, but were not allowed to use an arm swing to aid the jumps. Instructions were to jump for maximum height and to minimize their contact times in between jumps.

The single leg hop for distance required the athlete to begin standing on the designated testing leg with their toe touching the starting line, and their hands on their hips. Athletes were instructed to sink quickly and then jump as far forward as possible and land on two feet.

For the single leg triple hop for distance athletes began by standing on the designated testing leg with their toe touching the starting line and hands on their hips. The athletes were instructed to take three maximal jumps forward as far as possible on the testing leg and land on two legs of the final jump.

Participants were given 2 practice jumps before the specific jump test was conducted. The jumps were separated by a 2 minute rest period to ensure sufficient recovery. Athletes performed jumps in comfortable clothing and running shoes. All trials were averaged and used in the data analyses.

Data collection

Swift timing lights (Swift Performance, University of Southern Cross, Australia) were utilized to record the time (80Hz) from the start signal to when the athlete reached the 10 m line and broke the double beam of the timing lights. A microphone attached to a wooden start clapper was connected to the timing light handset, which triggered when the appropriate sound threshold was broken. A portable Kistler Quattro force plate (Kistler, Switzerland) operating at 500Hz was used to assess leg power for all vertical jumps. Horizontal jump assessments for distance were performed into a jump sandpit. The horizontal distance was measured from the start line to the jump landings closest point to the start line using a metal tape measure.

Data analysis

Force-time curves of the SJ, CMJ and SLJ were analysed to determine the vertical displacement, peak and average take-off force, ground contact time (SLJ only), stiffness (SLJ only) and peak and average take-off power (Kistler software, Switzerland). The athlete's bodyweight was subtracted from the force-time curves. The force-time curves were then integrated with respect to time to obtain the vertical take-off impulse. Vertical take-off velocity, vertical jump displacement, and power were then calculated as:

$$v = I/m$$
$$h = v^2/2g$$
$$P = Fv$$

Where v = vertical velocity at take-off ($m·s^{-1}$), I = vertical take-off impulse (N.s), m = body mass (kg), h = peak displacement of the centre of gravity above the height of take-off (m), g = gravitational constant of 9.81 ($m·s^{-2}$), P = power (W), and F= force (N). Jump power was calculated for the concentric phase. Peak force was defined as the highest vertical force reading for the take-off movement. All force and power values were normalized to the athlete's body weight (BW and W/kg) respectively.

Statistical analysis

Means and standard deviations were calculated for each variable. A stepwise multiple regression analysis was used to determine the best predictors of 10 m sprint performance. The data from a minimum of five to ten participants is required for each predictor measure in a linear equation for statistical strength (Howell, 1992). Therefore, a maximum of two predictor variables that had a statistically significant linear relationship with the dependant variable was utilised in these predictor equations. A linear regression analysis was used to quantify the relationships between the dependent variables and selected anthropometrical, force and power independent variables. The predictive strengths of each variable were ranked according to the product of the regression coefficient – beta (β) and the standard deviation for repeated measurements of each variable. The slope of the regression line is known as the regression coefficient beta (β) (i.e. straight line equation is y = βX + a where y = outcome measure, X = predictor measure, and a = the constant intercept). The regression coefficient beta indicates the amount of difference (increase or decrease) in the outcome measure (y) with a one-unit difference in the predictor measure (X) (Howell, 1992). Pearson's product-moment correlation coefficient was also used to establish relationships between independent variables. Statistical significance was set at $p < 0.05$ for all analyses. The number of statistical tests that would be likely to return a significant result by chance alone (Type 1 error) can be calculated by multiplying the alpha level by the total number of tests conducted (Hunter et al., 2004). It is possible that 1 returned significant result would likely have occurred by chance alone due to 25 statistical tests being conducted (i.e. 0.05 x 25). All statistical procedures were performed using SPSS for windows (version 11.5).

RESULTS

The results for all sprint, anthropometric and jump measures are presented in Table 1. Sprint times for the early acceleration sprint (10 m) ranged from 1.94 s to 2.14 s. The strongest overall linear model from the stepwise multiple regression that predicted 10 m sprint performance attested to the sprinters explosive ability to produce power during the countermovement jump (CMJ) test. This model which explained 63% of the performance variability is outlined below:

$$\text{10 m Sprint time (s)} = 2.554 - 0.015 \text{ CMJ Average Power (W/kg)}$$

$$r = 0.79,\ r^2 = 0.63,\ p < 0.01,\ SEE = 0.04,\ \%SEE = 2.0.$$

The Pearson correlation coefficients of all the jump kinetic and performance variables with 10 m sprint performance from a block start are summarized in Table 2. Squat jump (SJ) average power and peak power, CMJ average power and peak power, average force and peak force each had a significant ($p \leq 0.05$) correlation with 10 m sprint performance from a block start. The range of correlations was r = -0.70 to -0.79.

Predictors of 10 m sprint performance

CMJ kinetics was the highest ranked predictive test of 10 m sprint performance, as shown in Table 3. CMJ average and peak take-off power of 1 W/kg (3% and 1.5% respectively) to both result in a decrease of 0.01 s (0.5%) in 10 m sprint performance. An increase in CMJ average force by 0.1 BW (9%) was predicted to result in a 0.03 s (1.5%) reduction in 10 m sprint time. Further, an increase in SJ average and peak take-off power of 1 W/kg (3.5% and 1.5% respectively) was predicted to result in a 0.01 s (0.5%) reduction in 10 m sprint time.

DISCUSSION

A greater understanding of the requirements of competitive male sprint athlete start and acceleration performance is required before effective testing, monitoring and training can be developed. The purpose of the research was to identify the jump kinetic determinants of sprint acceleration performance from a block start. The results of the present study revealed strength/power qualities to be significantly related to 10 m sprint performance from a block start. In nearly all instances force and power measures from the vertical jump assessments were revealed to be the best predictors of 10 m sprint time. This indicates the importance of power production from the leg musculature in sprint performance. Specifically, the average power produced during the countermovement jump (CMJ) produced the best indication of sprint ability. This jump assessment is performed with a rapid

Table 1. Means ± standard deviations, minimums and maximums for sprint performance, anthropometric, and jump performance measures.

Parameters	Mean	±	SD	Min	Max
Sprint performance measures					
10 m sprint (s)	2.04	±	.06	1.94	2.14
Anthropometric measures					
Shoulder width (cm)	41.1	±	2.1	37.6	44.2
Hip width (cm)	27.6	±	1.5	26.1	30.9
Femur length (cm)	44.4	±	2.0	41.2	47.4
Tibia to floor length (cm)	49.2	±	3.7	44.4	56.0
Tibia length (cm)	40.5	±	1.8	38.5	44.5
Squat Jump measures					
Height (cm)	52.9	±	4.6	47.2	61.4
Average power (W/kg)	28.4	±	3.7	22.8	33.7
Peak power (W/kg)	60.6	±	5.7	51.1	68.5
Average force (BW)	1.04	±	.28	.61	1.5
Peak force (BW)	1.81	±	.46	1.07	2.72
Countermovement Jump measures					
Height (cm)	57.2	±	7.9	50.0	76.3
Average power (W/kg)	34.7	±	3.4	30.6	40.1
Peak power (W/kg)	62.0	±	5.2	55.1	70.2
Average force (BW)	1.15	±	.17	.98	1.52
Peak force (BW)	1.6	±	.23	1.41	2.13
Continuous jump measures					
Height (cm)*	40.4	±	6.8	25.9	45.5
Average power (W/kg)*	46.1	±	8.2	30.5	54.2
Peak force (BW)*	5.87	±	.97	4.69	7.12
Contact time (ms)*	199	±	31	167	249
Stiffness (kN/m)*	31.42	±	10.1	16.45	48.00
Single leg hop for distance					
Block front leg (m)	2.09	±	.09	1.99	2.26
Block back leg (m)	2.10	±	.10	1.99	2.27
Single leg triple hop for distance					
Block front leg (m)	6.90	±	.21	6.68	7.30
Block back leg (m)	6.90	±	.40	6.31	7.53

Note: * = average across the three series of five continuous jumps.

stretching of the lower limb musculature whilst it is also contracting at a high velocity. This suggests that an athlete's relative explosive ability of their hip and knee extensors is critical to sprint performance. In fact the stored elastic energy has been suggested to be necessary to sprint performance (Mero et al., 1992). Correlations ranging from r = 0.48 - 0.70 have been reported between CMJ performance and the velocity produced during the early acceleration phase when sprinting (Bret et al., 2002; Kukolj et al., 1999; Mero et al., 1983), which is similar to those identified in the present study.

Not only was the power generated during a CMJ important to acceleration performance but the power generated during a squat jump (SJ) also was identified through linear regression as a predictor of sprint ability. In the first few steps of sprint running, the propulsion (concentric action) phase has been reported to be 81.1% of the total step duration (Mero, 1988). Therefore it is no surprise that strong correlations of r = -0.72 to -0.73 were revealed between SJ power outputs and 10 m sprint time in the present study. These findings are in accordance with the range of correlations (r = 0.63 – 0.86) reported between SJ ability and sprint acceleration performance (Mero et al., 1983; Morin and Belli, 2003; Young et al., 1995). The findings of the present study further emphasise the important association between the generation of high levels of concentric power and acceleration sprint running.

It was expected that the relationships between jump tasks and sprint acceleration would be greater in the horizontal than the vertical jumps due to the direction of force application and take-off angles. Interestingly the single leg hop and single leg triple hop for distance were not identified as predictors of sprint acceleration. These jump assessments are similar to that of sprint running as they are both

Table 2. Pearson correlation coefficients between 10 m sprint performance and anthropometric, and jump performance measures.

Parameters	r		r^2	P value
Anthropometric measures				
Shoulder width (cm)	.18		.03	.617
Hip width (cm)	.22		.05	.538
Femur length (cm)	.40		.16	.248
Tibia to floor length (cm)	.42		.17	.232
Tibia length (cm)	.50		.25	.137
Squat Jump measures				
Height (cm)	-.28		.08	.466
Average power (W/kg)	-.72	*	.52	.028
Peak power (W/kg)	-.73	*	.53	.026
Average force (BW)	-.58		.34	.102
Peak force (BW)	-.66		.43	.054
Countermovement Jump measures				
Height (cm)	-.13		.02	.748
Average power (W/kg)	-.79	*	.63	.011
Peak power (W/kg)	-.77	*	.59	.016
Average force (BW)	-.78	*	.61	.013
Peak force (BW)	-.70	*	.49	.035
Continuous jump measures				
Height (cm)	.09		.01	.815
Average power (W/kg)	-.19		.03	.631
Peak force (BW)	-.21		.05	.580
Contact time (ms)	.47		.22	.202
Stiffness (kN/m)	-.41		.17	.272
Single leg hop for distance				
Block front leg (m)	-.30		.09	.435
Block back leg (m)	-.23		.05	.548
Single leg triple hop for distance				
Block front leg (m)	.24		.06	.531
Block back leg (m)	.33		.11	.392

* $p \leq 0.05$.

performed horizontally. It is therefore somewhat perplexing as to why insignificant weak correlations (r = -0.30 to 0.33) were discovered between these jumps and 10 m sprint performance. Nesser and colleagues (1996) reported a strong relationship (r = 0.81) between a horizontal 5-step jump and 40 m sprint time. Maulder and Cronin (2005) also reported strong relationships between 20 m sprint performance and horizontal single leg hop and single leg triple hop for distance (r = -0.74 and r = -0.86 respectively). Possible reasoning for the differences identified in the present study and the findings of Nesser and colleagues (1996), and Maulder and Cronin (2005) may have been the different characteristics of the subjects utilised in the studies. Perhaps the preconception to use distance as a performance measure for the predictability of horizontal jump measures to sprint performance is effective for athletes whom participate in sports which require a various range of sprint running expressions but invalid for competitive level male sprinters. Conceivably more sensitive measures such as average power and average force produced during the horizontal jumps would better reflect what is occurring during sprint running than jump distance only. This was made evident in the vertical jumps with force and power measures being better predictors of sprint performance than height only in the current study. The use of vertical height measures to gauge performance level in gymnasts has been shown to be inadequate (Bradshaw and Le Rossignol, 2004). It is acknowledged that access to more advanced dynamometry would be required and field tests are more appropriate to administer, but with the advancement of technology into portable equipment it may be more appropriate to utilise these types of devices to better gauge the athletes horizontal jumping ability.

It has been suggested that particular anthropometric measures are pre-requisites for good athletic performance in various sports (Kukolj et al., 1999). Interestingly the anthropometric dimensions

Table 3. Linear regression predictors of 10 m sprint performance. All models are statistically significant ($p < 0.05$).

Rank	Predictor	Pearson correlations			Linear regression			
		r	r^2	P value	β	β x SD	SEE (s)	%SEE
1	Countermovement jump average power (W/kg)	-.79	.63	.011	-.015	-.050	.04	2.0
2	Countermovement jump average force (BW)	-.78	.61	.013	-.285	-.049	.04	2.0
3	Countermovement jump peak power (W/kg)	-.77	.59	.016	-.009	-.047	.04	2.0
4	Squat jump peak power (W/kg)	-.73	.53	.026	-.008	-.046	.05	2.5
5	Squat jump average power (W/kg)	-.72	.52	.028	-.012	-.045	.05	2.5
6	Countermovement jump peak force (BW)	-.70	.50	.035	-.194	-.044	.05	2.5

measured in this study revealed poor insignificant (r = 0.18 – 0.50) relationships with sprint acceleration. Hunter and coworkers (2004) reported height and leg length to be a good predictors of acceleration phase velocity (r = -0.64 and r = -0.56 respectively). It is still unclear whether possessing longer lower limbs is advantageous to acceleration performance as it is possible that the longer leg length would lead to an increased step length (via a longer stance distance) but it may have an adverse effect on step frequency due to a greater moment of inertia about the hip joint (Hunter et al., 2004). The lack of statistical strength to identify the leg length measures as predictors of acceleration performance in the present study compared to that of Hunter and coworkers (2004) may be due the smaller subject pool used (36 vs. 10 subjects) or types of subjects used (male and female sports participants vs. competitive male sprinters). More research is required to gain a better understanding as to whether or not physical stature particularly limb lengths are important for sprint acceleration performance.

CONCLUSION

The results of this study provide further evidence suggesting that the relative explosive leg power in either the CMJ or SJ is an important aspect of sprint performance, especially during the early acceleration phase. The CMJ and SJ are therefore recommended as good field-tests to predict 10 m sprint performance from a block start due to the similar properties of force development associated with sprint running. Coaches of track athletes should consider the CMJ or SJ as useful training exercises to improve acceleration which may lead to an improvement in sprint performance. However, the CMJ or SJ need to be incorporated into a training study to validate the effectiveness of these exercises in attempting to improve sprint acceleration performance. Future research directions should include larger samples of elite sprinters and involve the continual monitoring of the physical attributes and sprinting performance of the sprinters in order to determine how changes in these physical attributes would relate to changes in 10 m sprint performance from a block start.

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✉ **Peter Maulder**
Institute of Sport and Recreation Research New Zealand, Auckland University of Technology, Private Bag 92006, Auckland 1020, New Zealand.

AUTHORS BIOGRAPHY

Peter S. MAULDER

Employment

Speed and strength conditioning consultant through the Auckland University of Technology's Sports Performance Centre for the New Zealand Academy of Sport.

Degrees

BSR, MHSc (Hons)

Research interest

Biomechanics of sprint running, training strategies for acceleration and maximum sprint running.

Email: peter.maulder@aut.ac.nz

Elizabeth J. BRADSHAW

Employment

Lecturer in the School of Exercise Science at Australian Catholic University in Melbourne and Sports Biomechanics consultant for athletes and coaches from, for example, the New Zealand Academy of Sport and Monash University.

Degrees

B. Ed., B.App, Sci (Hons), PhD

Research interest

Biomechanics of sports technique and injury mechanisms.

Biomechanics and motor control of target-directed running.

E-mail:
e.bradshaw@patrick.acu.edu.au

Justin W.L. KEOGH

Employment

Lecturer in the Division of Sport and Recreation at the Auckland University of Technology.

Degrees

BHMS (Hons)

Research interest

Sports biomechanics, kinanthropometry, motor control, benefits of resistance training.

E-mail: justin.keogh@aut.ac.nz

KEY POINTS

- The relative explosive ability of the hip and knee extensors during a countermovement jump can predict 10 m sprint performance from a block start.
- The relative power outputs of male competitive sprinters during a squat jump can predict 10 m sprint performance from a block start.