SPECIFIC-OVERLOAD CHARACTERISTICS OF HORIZONTAL JUMP EXERCISES IN COMPARISON TO THE BLOCK START

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The aim of this study was to compare kinetic data at the ankle, knee and hip joint between the block start and three variations of horizontal jump exercises. Eight male sprinters (100 m PB 10.88 ± 0.18 s) performed each exercise whilst external force (1000 Hz) and 3D kinematics (250 Hz) were collected. Internal kinetics at the ankle, knee and hip joint were calculated using inverse dynamics. Key results indicated significantly increased moment and power at the ankle joint in the horizontal jumps compared with the block start, but no differences in power at the knee and hip joint. The present study highlighted specific-overload at the ankle joint but also similarity in the organisation of power across all joints. The information provides coaches and athletes with key biomechanical information to inform exercise selection for physical preparation programmes.

KEY WORDS: Sprint start, sprint training, training theory, strength and conditioning

INTRODUCTION: Performance in the starting block phase is of key importance to overall performance in the short sprint events (Willwacher et al., 2013) and is characterised by generating large extensor moments and power at the ankle, knee and hip joint (Brazil et al., 2016a; Mero et al., 2006). As such, there is great desire to improve block performance by utilising the most effective training exercises although there is a lack of mechanical evidence to help coaches make the best decisions for their physical preparation programmes. According to the principles of training, an exercise must overload relevant characteristics of the sporting task, in a specific manor, so that subsequent physiological adaptations will result in performance improvement (Mateveyev, 1981). Therefore, although certain mechanical differences (overload) are required for physiological adaptation, there must still be similarities (specificity) in the mechanics of the two skills for these adaptations to be most effective (Irwin et al., 2007; Young et al., 2006). Previously, Brazil et al. (2016b) identified that average extensor moment at the front ankle, knee and hip joint and average positive extensor power at the front knee joint were key determinants of block performance. Other research (Mero et al., 2006) has established the dominant role of the hip joint in generating leg extensor energy, and high extensor joint power at the ankle. For an exercise to therefore be effective, these key mechanical determinants of performance must be exposed to a specific-overload stimulus for a desired adaptation to take place that can consequently improve performance (Siff & Verkoshansky, 1999; Irwin et al., 2007).
Ballistic exercises that involve jumping are commonly used by sprint coaches (Bulger et al., 2016), and those executed in the horizontal direction are typically better related to sprint acceleration performance (Maulder & Cronin, 2006). However, a comparison of the internal kinetics between these exercises and the block start does not currently exist to understand the efficacy of these training exercises to enhance performance. Therefore, the aim of this study was to compare kinetic data at the ankle, knee and hip joint between the block start and three variations of horizontal jumping in order to understand the specific-overload characteristics and potential effectiveness of these jumping exercises to improve starting block performance.

METHODS: Eight male sprinters (21 ± 4 years, 1.81 ± 0.07 m, 77.25 ± 6.86 kg) with 100 m PB ranging from 10.64-11.20 s (10.88 ± 0.18 s) gave written informed consent to participate in this study following ethical approval. External force and 3D kinematics were collected during three to six repetitions of the following exercises: Block start (BS), bilateral horizontal jump (BL; normal bilateral stance), split stance horizontal jump (SS; one foot in front of the other to emulate the nature of the block start), and unilateral horizontal jump (UL; single leg stance). For analysis purposes, the front leg in the block start was used and compared between all exercises, and the average of all trials were used. The duration of the block phase was defined between the first derivative of the force-time curve > 500 $N.s^{-1}$ and resultant force < 50 N (Brazil et al., 2016a). For each of the jumping variations, the phase of interest to match the nature of the block start was defined between the onset of hip extension and vertical force < 10 N (i.e. leg extension).
Force data were collected using instrumented starting blocks (Willwacher et al., 2013) for the block start (10000 post processed to 1000 Hz), and a force platform for all jump variations (9287BA, Kistler, 1000 Hz) and were low-pass filtered (4^{th} order Butterworth, 120 Hz cut-off) prior to analysis. Kinematic data were collected using a 15 camera motion capture system (Vicon, Oxford Metrics, UK, 250 Hz), calibrated to residual errors of < 0.3 mm using a 240 mm calibration wand. Retro-reflective markers (14 mm) were attached bilaterally to the: iliac crest, posterior superior iliac spine, anterior superior iliac spine, greater trochanter, lateral and medial femoral epicondyles, lateral and medial malleoli, first and fifth metatarsal heads, calcaneus, and head of the second toe. Technical clusters comprising four markers were attached towards the distal end of the thigh and shank segments. Processing of kinematic and kinetic data was performed using Visual 3D (C-Motion Inc, Germantown, USA). Raw marker coordinates were low-pass filtered (4^{th} order Butterworth) at a cut-off of 12 Hz determined from residual analysis. Newton-Euler inverse dynamics procedures were used to calculate resultant joint moment at the front leg ankle ($_{ANK}$), knee ($_{KNE}$) and hip ($_{HIP}$) joints and were resolved in the proximal segments coordinate system. Only x-axis (flexion-extension) data were reported due to the predominant sagittal nature of sprinting. A virtual landmark that projected the MTP joint centre onto the surface of the block was used to define centre of pressure during BS (Brazil et al., 2016a). In order to assess overload characteristics, average extensor moment (M) and average positive power during joint extension (P) were calculated. These variables were chosen based on previous evidence as being key determinants of performance (Brazil et al., 2016b). To assess the specific nature of moment and power profiles, ensemble average plots for joint moment and power were produced and normalised to 100% of movement duration using a cubic spline. To investigate the differences in movement duration, moment and power between BS and all jumps, a repeated measures ANOVA was utilised and Bonferonni *post-hoc* tests were conducted when significant main effects were found. Statistical significance was accepted at $P < 0.05$.

RESULTS: ANOVA results revealed significant main effects for only M_{ANK}, M_{HIP} and P_{ANK}. Post-hoc comparisons are detailed in Table 1 and indicated no significant movement duration differences between BS and any of the jumps. At the joint kinetic level, M_{ANK} and P_{ANK} were significantly greater in all jumps compared with BS and were of largest magnitude for UL. Significantly greater M_{HIP} was also observed in SS and UL compared with BS and again was largest for UL (Table 1). Figure 1 highlighted many similarities in the pattern of joint power at the ankle, knee and hip joint and reinforced the discrete data by detailing the overloading nature at the ankle joint (Figure 1).

Table 1. Group Mean ± SD data for the Block Start (BS) and horizontal jumps (BL, SS and UL).

	BS	BL	SS	UL	Symbol
Duration (s)	0.367 ± 0.019	0.336 ± 0.037	0.366 ± 0.028	0.398 ± 0.047	
M_{ANK} (Nm)	63.20 ± 11.90	118.03 ± 17.50	95.86 ±19.35	176.56 ± 27.84	+ ł ‡
M_{KNE} (Nm)	88.43 ± 27.64	78.49 ± 19.11	73.31 ± 15.56	102.56 ± 26.01	

M_{HIP} (Nm)	122.37 ± 23.32	151.29 ± 23.97	160.81 ± 26.02	218.81 ± 19.74		ł	‡
P_{ANK} (W)	302.31 ± 74.21	491.22 ± 116.20	494.69 ± 109.53	855.02 ± 260.41	+	ł	‡
P_{KNE} (W)	452.33 ± 144.74	464.02 ± 139.22	501.01 ± 98.21	511.68 ± 165.16			
P_{HIP} (W)	622.86 ± 117.97	557.56 ± 121.58	537.51 ± 102.69	537.62 ± 93.83			

Symbols denote ($P < 0.05$) differences between BS and BL (+), SS (ł), and UL (‡).

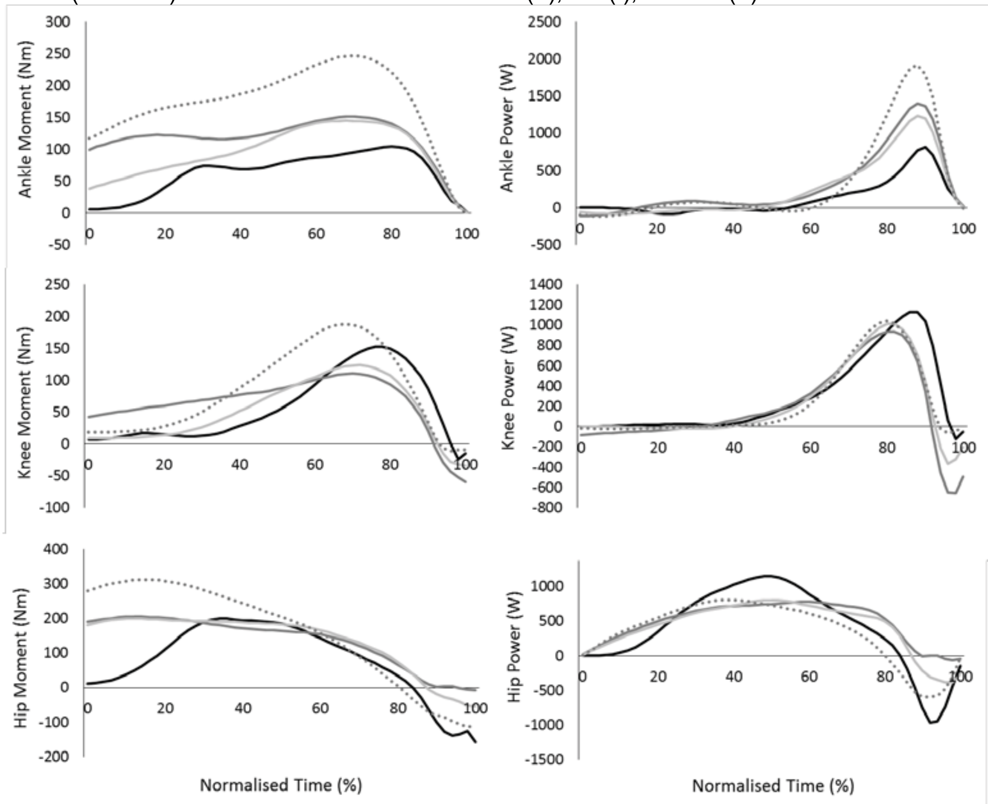

Figure 2. Joint moment- (left) and power- (right) normalised time curves for the front ankle (top), knee (middle) and hip (bottom) joint during BS (black), BL (dark grey), SS (light grey) and UL (dotted).

DISCUSSION: The primary aim of this study was to compare kinetic data at the ankle, knee and hip across the block start and three variations of horizontal jump in order to gain insight into specific-overload characteristics and the potential effectiveness for these exercises to improve block performance.

With respect to the principles of training, for an exercise to elicit an adaptation that can increase the performance of a given sporting task, there must be an overload stimulus that shares relevant characteristics with the sporting task (Mateveyev, 1981; Siff & Verkoshansky, 1999). In the present study it is clear that the three variations of horizontal jump were able to overload the ankle joint at the moment and power level (Table 1, Figure 1). Ankle joint moments were higher throughout the duration of each movement, whilst joint power was greater from approximately 60% of movement time encompassing the phase in which peak extensor power occurred. Therefore, each jump variation would appear to elicit a specific-overload stimulus at the ankle joint in relation to the block start, with the greatest being observed when performed unilaterally. The other notable difference between the block start and horizontal jumps were for hip joint moment (Table 1). Although magnitudes of M_{HIP} were significantly greater in SS and UL compared with BS, Figure 1 reveals that this difference was at the beginning of the movement and these were much smaller once extensor moments in BS had initially increased. Furthermore, no differences in P_{HIP} were observed and therefore the overall efficacy of the horizontal jumps to specifically overload the hip joint were minimal. No discrete differences were found at the knee joint in comparison with the block start (Table 1) indicating a lack of global overload at the knee joint. Temporal differences in

joint moment indicated localised overload, but for joint power, none of the horizontal jumps clearly provided a heightened stimulus above that during BS.
Temporal similarities in joint power curves provide mechanical explanation as for why horizontal jumps are related to sprint acceleration performance (Maulder & Cronin, 2005), and how they may be useful in refining neuromuscular potential for improved utilisation of physical qualities for block start (Siff & Verkoshansky, 1999). However, the absence of an overload stimulus for P_{KNE} and P_{HIP} may reduce the overall effectiveness of these exercises to improve block start performance (Brazil et al., 2016b), and other exercises must be sought to provide a specific-overload stimulus at these joints. Manipulating the execution of horizontal jumps by altering foot positioning had its greatest effect at the ankle joint, although joint moment patterns were also inconsistent between BL, SS and UL therefore highlighting how manipulating the constraints of a training exercise can alter the mechanical loading and potential stimulus for adaptation. Whilst the current study has shown that horizontal jumps may be effective at stimulating specific ankle adaptations, the current comparisons were limited to temporal similarities. Further work should consider investigating joint kinetic data as a function of joint angle (Irwin et al., 2007) in order to more completely understand the specific nature of these training exercises and overall differences in musculoskeletal demand between the block start and ballistic horizontal jump exercises.

CONCLUSION: Results indicated that horizontal jumping primarily elicited specific-overload at the ankle joint, and that the temporal organisation of joint powers were relatively similar between the block start and all variations of horizontal jumps. The potential for these exercises to improve starting block performance was therefore highlighted. This study has provided further evidence to support the necessary link between biomechanics and strength and conditioning in order to provide objective information to support exercise selection.

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