THE SPECIFICITY OF STRENGTH EXERCISES FOR SPRINT ACCELERATION

Yiannis Lambrianides and Glen Blenkinsop
School of Sport, Exercise and Health Science, Loughborough University, Loughborough, UK[2]

The purpose of the study was to use musculoskeletal modelling to examine the specificity of bounding and loaded countermovement jumps (CMJ) to sprinting acceleration. Ten male participants performed 10 m sprints, continuous bounding, and loaded CMJ's. A generic OpenSim model was scaled to each individual and used to calculate joint moments, angles and angular velocities during maximal trials in each condition. Peak moment, angle at peak moment and angular velocity at peak moment for the ankle, knee, and hip joints were determined and statistically analysed using pair-wise equivalence and non-inferiority tests. Compared to sprinting, peak moments at all joints were shown to be statistically non-inferior for bounding, but statistically inferior for loaded CMJ's. Compared to sprinting, knee and ankle joint angular velocities were statistically equivalent for bounding, but statistically different for loaded CMJ's. In terms of the specificity for strength and conditioning exercises, these results suggest that bounding may be considered as a specific exercise for acceleration, while loaded CMJ's may be less suitable.

KEYWORDS: joint moments, sprinting, strength and conditioning.

INTRODUCTION: The training principle of specificity suggests that for optimum transfer of training benefits to dynamic movement the components of the resistance training stimulus should be specific to the activity in terms of muscles involved, muscle action type, loading characteristics and range of movement (Sleivert and Taingahue, 2004). If this is followed to the extreme, all training would just mimic competition actions and demands. Such an approach is expected to produce efficient transfer to performance in the short term but may lead to negative results such as overtraining, muscle imbalances, increased injury risk and boredom (Young, 2006). In order to avoid training programmes exclusively consisting of body weight sprinting, resisted training is often employed, however such exercises should still follow the principle of specificity. Contrary to traditional heavy resistance exercises, resisted movement training allows for acceleration during the whole range of motion to enhance power and performance by executing movements used in sporting competition with additional resistance (Hrysomallis, 2012).

Sprinting is one of the most important components in athletics events such as short distance races, long jump and triple jump (Murphy, Lockie and Coutts, 2003). The outcome of many different sports can be determined by periods of sprinting, including games such as football, basketball, American football, rugby and field hockey (Lockie, Callaghan and Jeffriess, 2014). Sprinting may be categorised into three phases in terms of force production (speed generation): acceleration, maintenance of maximum speed and deceleration (Wild et al., 2011). Sprint performance during the acceleration phase has been found to be more strongly correlated to the horizontal impulse (Morin, Edouard and Samozino, 2011) and is believed to be dominated by explosive concentric muscle actions (Sleivert and Taingahue, 2004). Consequently, it has been suggested that exercises with similar characteristics would be suitable both for training and testing (Hori et al., 2007). Several strength and conditioning exercises aimed at enhancing sprint performance, including sprint drills, weight training and plyometrics, have been investigated (Rimmer and Sleivert, 2000; Ronnestad et al., 2008), and while some have been found to improve performance, there is still some uncertainty regarding the specific mechanisms of improvement (Lockie et al., 2012).

Sprint bounding is a multiple jumping exercise for maximum distance using a one-foot take-off like the step phase of the triple-jump. While some authors believe bounding may not be specific to sprinting (Young, 1992), others suggest it may be useful for sprint acceleration due to the longer ground contact times during this phase of the sprint (Wild et al., 2011). Loaded countermovement jumping (CMJ) can potentially enhance physical qualities such as maximum muscle force which may transfer to increased acceleration during sprinting (Kraska et al., 2009, Comfort et al., 2014). While an optimum load has not been established (Harris et al., 2008), higher loads up to 90% of 1 repetition max (1RM) are expected to yield higher force production. However, higher loads could also adversely alter the biomechanics of the jump by causing a reduction in speed and therefore power (Weber et al., 2008; Hori et al., 2008). Therefore, lighter loads of around 30% of 1RM are suggested to be more appropriate for enhancing sprint acceleration performance (Baker, 1996). While a range of strength and conditioning training exercises may be used to help enhance performance, no optimal training programme to improve acceleration has been established (Turner et al., 2015). The purpose of this study was to use joint moments, angles, and angular velocities from musculoskeletal modelling to determine and compare the specificity of bounding and loaded CMJ as strength and conditioning exercises for sprint acceleration.

METHODS: Ten male (mean ± SD: age 23.7 ± 2.5 years; height 1.81 ± 0.09 m; body mass 80.85 ± 6.43 kg; 1RM in back squat 118 ± 28.85 kg) university students volunteered to participate in this study. All participants were active, free of any musculoskeletal injuries in the previous six months, participated competitively or recreationally in sports which require acceleration (athletics n=4, football n=3 and basketball n=3) and had experience of basic sprint and gym training. All participants provided written informed consent for the study that was approved by the University Ethical Approval Committee.

Kinetic data were collected via two 900 X 600 mm force plates (Kistler 9281EA, Kistler, Winterhur, Switzerland) at a sample rate of 1000 Hz. Three-dimensional kinematic data were collected using twelve T40-s and six T20-s Vicon cameras (Vicon, Oxford Metrics Group, UK) at a sample rate of 500 Hz. Cameras were positioned to provide a 3 X 5 X 3 m (XYZ) capture volume centred on the force plates with the positive axes pointing to the right (X), forwards, (Y), and up (Z). Kinematic and kinetic data were synchronised in the Vicon hardware (MX Giganet box, Vicon, Oxford Metrics Group, UK). A marker set consisting of 47 retro-reflective spherical markers of 14 mm diameter was used to divide the body into 14 segments. At least three markers were placed on bony landmarks of each segment to create individual segment local coordinate systems in the motion analysis software (Vicon Nexus 2.7, Oxford Metrics Group, UK).

Participants attended a single data collection session consisting of a 15-minute warm-up and practice trials before completing 3 trials in each of the three conditions (sprinting, bounding, loaded CMJ). Each sprinting trial was completed so the participants fourth foot contact landed completely within the area covered by the two force plates during a 10 m maximal effort sprint from a static three-point start. Bounding trials consisted of several continuous bounding contacts, with at least 2 contacts before and two contacts after the measured contact, ensuring the same foot contacted the force plate area as that during the sprint testing. During both sprinting and bounding trials, participants were instructed to perform the task naturally and to not alter their steps in order to strike the force plate, with the whole of the foot striking the force plate required for a successful trial to be counted. Weighed CMJ's were performed with the participant standing on the two force plates, with one foot on each force plate, holding a bar (on shoulders in back squat position) weighing 30% of their 1RM for a back squat. Participants were asked to perform maximal effort CMJ with a countermovement that dropped to a knee flexion of at least 90 degrees. Extra trials were allowed if the participant was unhappy with any trial, but to prevent fatigue a maximum of 6 trials in each condition was enforced. A rest period of at least three-minutes was used between attempts to ensure adequate recovery between maximal effort trials. The best trial for each trial in each condition was used for analysis.

A generic OpenSim model (Rajagopal et al., 2016) was scaled to each participant based on their mass and pairs of markers from experimental data collection, using proximal and distal points to determine appropriate scaling factors for limb lengths. Data were then modelled using the OpenSim inverse kinematics function before joint angles and force plate data were filtered with a fourth order zero-lag Butterworth filter with a lowpass cut-off frequency of 20 Hz, determined from residual analysis. Force plate data was subsequently combined with kinematic data through the OpenSim inverse dynamics function to determine joint moments of the target leg for hip and knee extension and ankle plantar flexion.

Peak joint moments and joint angles and angular velocities at these peak moments were determined for each joint during each task. Lesaffre (2008) suggests that null hypothesis significance testing, such as ANOVA's, should not be used to demonstrate comparability when a non-significant result is sought. Consequently, two one-sided tests (TOST) were performed to assess the equivalence in joint angle and angular velocity at peak moments (Lesaffre, 2008). To determine if the peak joint moments during sprinting were not significantly higher than those during bounding and weighted CMJ's, a non-inferiority test was performed (Lakens, 2017). A significant level of 0.05 was used for all tests, and prior to statistical testing, all data were found to be normally distributed by the Shapiro-Wilk test.

Table 1: Mean and standard deviations for peak moments ($N \cdot m \cdot kg^{-1}$), and joint angle (°) and angular velocities ($° \cdot s^{-1}$) at peak moments during sprinting, bounding, and loaded CMJ's.

	Sprinting	Bounding	Loaded CMJ
Peak joint moment ($N \cdot m \cdot kg^{-1}$):			
Hip*	4.15 ± 0.83	4.20 ± 1.25	2.08 ± 0.52
Knee*	2.57 ± 1.31	3.71 ± 1.46	1.81 ± 0.34
Ankle*	2.28 ± 1.29	2.98 ± 1.16	1.88 ± 0.28
Joint angle at peak moment (°):			
Hip	40.9 ± 21.7	30.5 ± 18.9	84.0 ± 12.7
Knee*	36.6 ± 12.9	46.4 ± 9.4	104.4 ± 13.6
Ankle*	10.7 ± 14.7	14.5 ± 5.0	8.7 ± 5.3
Joint angular velocity at peak moment ($° \cdot s^{-1}$):			
Hip	-437.6 ± 79.4	-162.7 ± 147.3	-50.3 ± 63.8
Knee	-197.0 ± 157.1	-195.4 ± 120.8	-33.0 ± 99.3
Ankle	1.4 ± 83.0	23.5 ± 165.3	-225.6 ± 24.6

*Note: Statistically significant equivalence or non-inferiority ($p < 0.05$) between sprinting and bounding**

RESULTS: Peak joint moments were highest in bounding, followed by sprinting, and lowest in loaded CMJ for all three joints (Table 1). Hip moments were highest during all three tasks, with knee moments higher than ankle moments during sprinting and bounding, but the ankle moments marginally higher than knee moments during loaded CMJ (Table 1). Statistical analysis showed that peak ankle, knee, and hip joint moments during bounding were non-inferior to those during sprinting, however, peak ankle, knee, and hip joint moments during loaded CMJ's were found to be statistically inferior to those during sprint acceleration (Table 1). While joint angles at peak moments were found to be statistically equivalent between sprinting and bounding for the ankle and knee joints, this was not the case for the hip joint, which was more extended during bounding. No joint angles at peak moments were found to be equivalent during loaded CMJ's and sprinting, with joint angles markedly more flexed in the hip and knee, and less dorsi flexed at the ankle (Table 1). Similarly, no joint angular velocities were found to be equivalent for any joint between bounding and sprinting or between loaded CMJ and sprinting.

DISCUSSION: The aim of this study was to examine the specificity of bounding and loaded CMJ exercises to the acceleration phase of sprinting. Peak joint moments in the ankle, knee and hip joints in bounding were found to be significantly non-inferior to sprinting, whereas all three peak joint moments in loaded CMJ at 30% 1RM were found to be inferior. Similarly, ankle and knee joint angles at peak moments were found to be statistically equivalent between bounding and sprinting, but none of the joint angles at peak moments were found to be equivalent between loaded CMJ and sprinting.

CONCLUSION: In conclusion, based on peak joint moments and joint angles, bounding is a suitable strength and conditioning exercise for sprint acceleration, while loaded CMJ at 30% 1RM is less suitable. When aiming for peak specificity of training, coaches and athletes are advised to use bounding rather than loaded CMJ at 30% 1RM to enhance sprint acceleration performance.

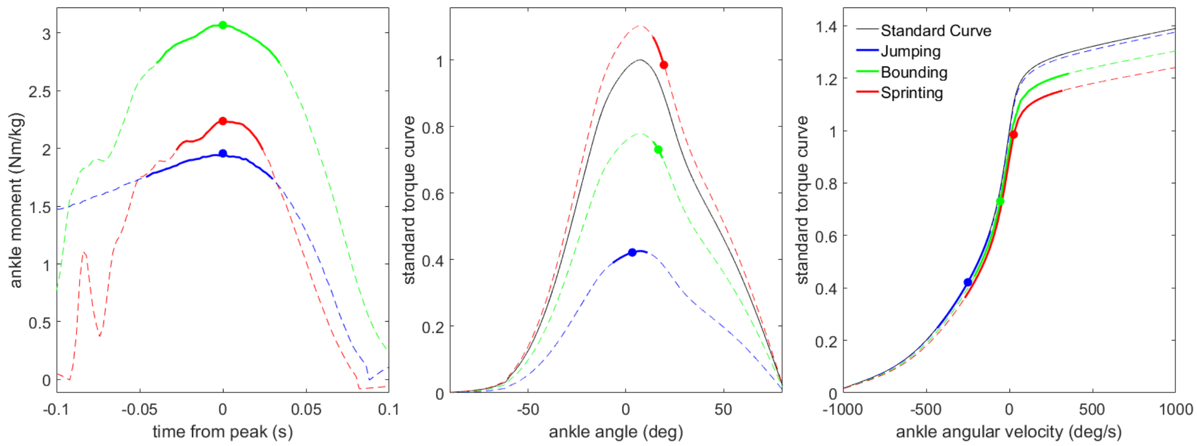

Figure 1: An example of the peak ankle joint moments (left), angle (middle), and angular velocity (right) during sprinting (red), bounding (green) and jumping (blue). The standard curve shows the maximum torque available at the optimum angle during isometric conditions.

REFERENCES

Hrysomallis, C. (2012). The effectiveness of resisted movement training on sprinting and jumping performance. *The Journal of Strength & Conditioning Research*, *26*(1), 299-306.

Lakens, D. (2017). Equivalence tests: a practical primer for t tests, correlations, and meta-analyses. *Social psychological and personality science, 8*(4), 355-362.

Lesaffre, E. (2008). Superiority, equivalence, and non-inferiority trials. *Bulletin of the NYU hospital for joint diseases, 66*(2).

Lockie, R.G., Murphy, A.J., Callaghan, S.J. and Jeffriess, M.D. (2014). Effects of sprint and plyometrics training on field sport acceleration technique. *The Journal of Strength & Conditioning Research, 28*(7), 1790-1801.

Lockie, R.G., Murphy, A.J., Schultz, A.B., Knight, T.J. and de Jonge, X.A.J. (2012). The effects of different speed training protocols on sprint acceleration kinematics and muscle strength and power in field sport athletes. *The Journal of Strength & Conditioning Research*, *26*(6), 1539-1550.

Murphy, A.J., Lockie, R.G. and Coutts, A.J. (2003). Kinematic determinants of early acceleration in field sport athletes. *Journal of sports science & medicine, 2*(4), 144.

Rajagopal, A., Dembia, C.L., DeMers, M.S., Delp, D.D., Hicks, J.L. and Delp, S.L. (2016). Full-body musculoskeletal model for muscle-driven simulation of human gait. *IEEE transactions on biomedical engineering*, *63*(10), 2068-2079.

Rimmer, E. and Sleivert, G. (2000). Effects of a plyometrics intervention program on sprint performance. *The Journal of Strength & Conditioning Research*, *14*(3), 295-301.

Ronnestad, B.R., Kvamme, N.H., Sunde, A. and Raastad, T. (2008). Short-term effects of strength and plyometric training on sprint and jump performance in professional soccer players. *The Journal of Strength & Conditioning Research*, *22*(3), 773-780.

Sleivert, G. and Taingahue, M. (2004). The relationship between maximal jump-squat power and sprint acceleration in athletes. *European journal of applied physiology*, *91*(1), 46-52.

Wild, J., Bezodis, N.E., Blagrove, R. and Bezodis, I.N. (2011). A biomechanical comparison of accelerative and maximum velocity sprinting: Specific strength training considerations. *Professional Strength and Conditioning*, *21*, 23-37.

Young, W. (1992). Sprint bounding and the sprint bound index. *Natl Str Cond Assoc J*, *14*(4), 18-21.

Young, W.B. (2006). Transfer of strength and power training to sports performance. *International journal of sports physiology and performance, 1*(2), 74-83.