LOWER BODY MUSCULOTENDON UNIT FUNCTION DURING BOUNDING, HURDLE JUMPING AND RUNNING

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To facilitate exercise prescription, this study compared the function of six lower limb musculotendon units during plyometric exercises with running. Fourteen distance runners performed overground running (3.89 m/s), bounding, and hurdle jumps. Computational simulations were used to compare musculotendon unit function, peak powers, and total work. Compared to running, the hurdle jumps had greater gluteus maximus peak power absorption (12.1%; SMD 0.65), and gluteus maximus (15.7%; SMD 0.51) and soleus (16.5%; SMD 0.92) total negative work. Hurdle jumps may be an appropriate exercise when higher eccentric loads of the gluteus maximus and soleus are required. Compared to running, bounding had increased gastrocnemius total negative work (63.8%; SMD 0.81) and may be suitable when eccentric overload of the gastrocnemius is desired.

KEYWORDS: plyometrics, strength training, distance runner, training adaptations, OpenSim.

INTRODUCTION: Over one-third of distance runners use plyometric exercises as part of their warm up routines or strength and conditioning programs (Blagrove, Brown, Howatson, & Hayes, 2020). Plyometrics are often implemented to enhance running performance and prevent injuries (Blagrove, Brown, Howatson, & Hayes, 2020). Common plyometric exercises include bounding, drop jumps, hopping, hurdle jumps, and skipping variations (Blagrove et al., 2020; Trowell, Vicenzino, Saunders, Fox, & Bonacci, 2019). Training exercises should be based on the fundamental principles of overload, progression, and specificity to maximise the transfer of training while minimising the risk of injury (Ratamess et al., 2009). A number of studies have provided important comparisons between the joint kinematics (McDonnell, Willson, Zwetsloot, Houmard, & DeVita, 2017; Sides, 2014) or joint kinetics (McDonnell et al., 2017) of plyometric exercises with running. However, net joint kinematics or kinetics cannot quantify the specific function of individual muscles due to the influence of tendon elastic energy, muscle co-contraction, biarticular muscles, passive forces, and the degrees of freedom redundancy problem (Schache, Dorn, Blanch, Brown, & Pandy, 2012). If plyometric exercises are to be used by distance runners during their warm up or training programs, then it is imperative to understand how the musculoskeletal demands compare to running for evidence-based training design and progression. Musculoskeletal modelling provides a tool for estimating individual musculotendon unit (MTU) properties using non-invasive procedures (Delp et al., 2007). The purpose of this study was to compare the function, peak power, and total work of six lower limb MTUs during bounding and hurdles jumps to overground running among distance runners.

METHODS: Fourteen trained distance runners (seven males and seven females) participated in this study. Participants were aged 27.8 ± 7.8 years, with a height of 177.0 ± 10.3 cm and weight of 63.2 ± 9.7 kg. Participants identified as middle distance track (n = 6), long distance track (n = 4), and long distance road (n = 4) runners. The average weekly running training volume among participants was 86.0 ± 22.1 km.

Participants performed running (3.89 m/s), bounding, and hurdle jumps on an indoor 110 m straight running track. Kinematic data were collected using a 22-camera Vicon motion analysis system (Oxford Metrics Ltd, Oxford, UK) sampling at 250 Hz. Ground reaction force (GRF) data were simultaneously captured using eight consecutive in-ground 900 x 600 mm Kistler force plates (Kistler, Amherst, New York, USA) sampling at 2000 Hz. The running speed of 3.89 m/s was chosen because this speed represented a regular training pace (≈ 4:17 min/km) while targeting the development of their aerobic system among this cohort of trained distance runners. During the running and bounding trials, participants were allowed a self-selected run-up to ensure the correct speed was achieved and maintained throughout the 20 m capture space. During the hurdle jumps, participants jumped over four consecutive 51 cm hurdles that were spaced 75 cm apart. The hurdle jumps were executed with feet contacting different force platforms so that GRFs for each limb could be independently collected during ground contact. Five trials were collected for each exercise and the middle repetition was analysed from each trial.

Computational musculoskeletal simulations were performed in OpenSim 4.0 software (OpenSim, California, USA) using experimental marker positions and GRF data as inputs. Joint moments were calculated using the residual reduction algorithm (RRA). MTU outputs were estimated using the computed muscle control (CMC) algorithm. The following MTUs were analysed: (i) gluteus maximus (GMAX); (ii) biarticular hamstring complex (HAMS); (iii) rectus femoris (RF); (iv) vastus muscle complex (VASTUS); (v) gastrocnemius lateralis (GLAT); and, (vi) soleus (SOL). Outcome measures included normalised peak power generation and absorption (W/kg) and total positive and negative work (J/kg). MTUs were classified as energy generators or absorbers according to their net mechanical work. Percentage change scores and standardised mean differences (SMD) were calculated relative to running. Effect size magnitudes < 0.20 indicate trivial, 0.20-0.59 indicate small, 0.60-1.19 indicate moderate, and values ≥ 1.20 indicate large sized effects in comparison to running.

RESULTS: Bounding had similar GMAX total negative work (-0.4%; SMD 0.01) and RF total positive work (1.4%; SMD 0.08) compared to running. Bounding had a large increase in VASTUS total positive work (23.2%; SMD 1.34) and a moderate increase in GLAT total negative work (63.8%; SMD 0.81) compared to running. GLAT total positive work during bounding (1.4%; SMD 0.06) was similar to running. There were small increases in SOL total peak positive work (12.4%; SMD 0.58) and negative work (9.9%; SMD 0.40) during bounding in comparison to running.

The hurdle jumps had a moderate increase in GMAX peak power absorption (12.1%; SMD 0.65) and a small increase in GMAX total negative work (15.7%; SMD 0.51) compared to running. Hurdle jumps had a large increase in VASTUS total positive work (41.2%; SMD 2.32) compared to running, while VASTUS total negative work (-0.1%; SMD 0.00) was similar to running. There was a moderate increase in SOL total negative work (16.5%; SMD 0.92) during the hurdle jumps in comparison to running. All remaining bounding and hurdle jumps MTU peak powers and total work were lower compared to running.

Figure 1 shows the percentage of positive and negative work relative to the total work performed by each individual MTU during running, bounding, and hurdle jumps.

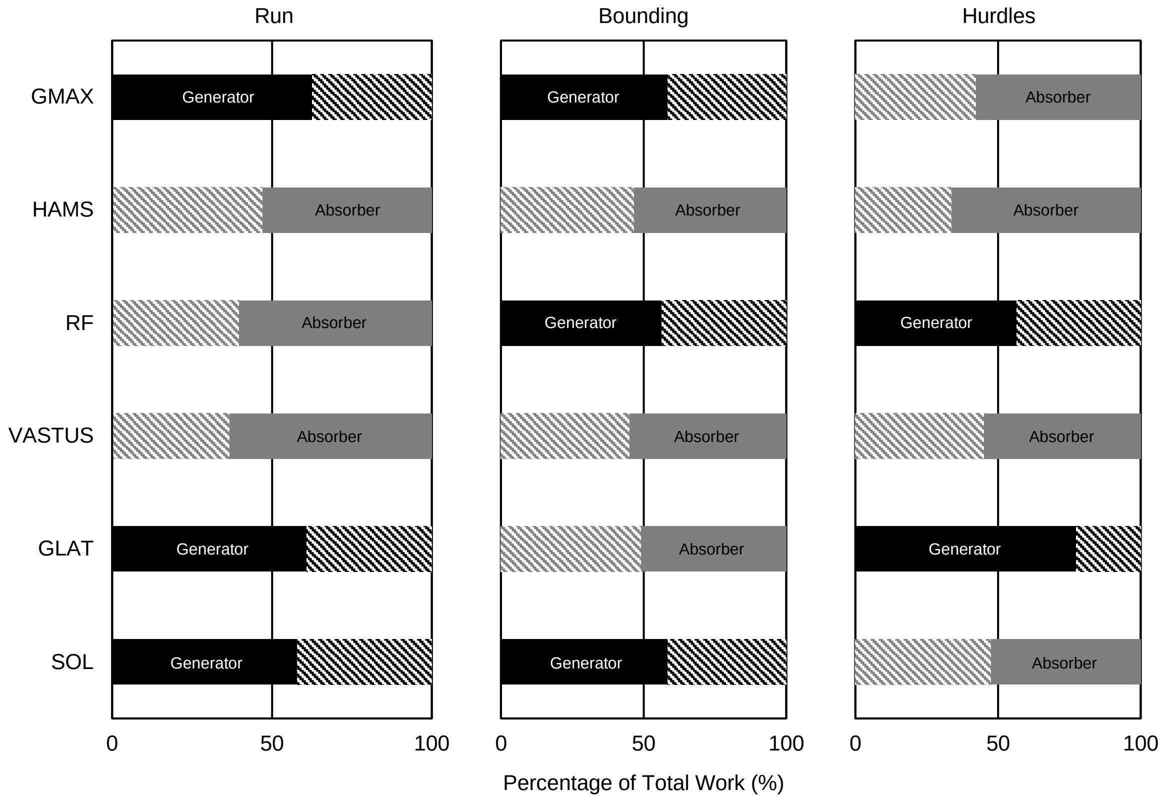

Figure 1: Functional indices of individual MTU net work during running, bounding, and hurdle jumps. The indices are dimensionless and calculated as the percentage of total positive or negative work relative to the sum of total positive and negative work. MTUs with greater total positive work relative to total negative work are expressed as energy generators. MTUs with greater total negative work relative to total positive work are expressed as energy absorbers.

DISCUSSION: This study reveals important insights regarding MTU function during bounding and hurdles jumps compared to overground running. The present findings agree with past research showing that GMAX, GLAT, and SOL muscles behave as net energy generators, while HAMS, RF, and VASTUS muscles behave as net energy absorbers, across the running stride cycle (Dorn, Schache, & Pandy, 2012; Schache et al., 2011). This distribution of energy was relatively consistent among the training exercises, albeit with some exceptions.

GMAX switched to a net energy absorber during the hurdle jumps due to a small increase in total negative work, and a large decrease in total positive work, compared to running. The hurdle jumps also had greater GMAX peak power absorption than running. The hurdle jumps requires a large amount of vertical oscillation to clear the hurdles and a smaller range of hip motion during ground contact compared to running. These movement patterns demand greater eccentric work from GMAX to absorb kinetic energy during landing. RF functioned as a net energy generator during bounding and hurdle jumps, but behaved as a net energy absorber during running. This difference was underpinned by large decreases in RF total negative work during the plyometric exercises. This may be the result of a lower eccentric demand for RF during the ground contact and initial swing phases of the hurdle jumps and bounding. While the VASTUS behaved as a net energy absorber across all exercises and running, the hurdle jumps and bounding had greater VASTUS total positive work than running. Compared to running, hurdle jumps and bounding require greater propulsion of the centre of mass applied over a longer period of ground contact. Thus, the hurdle jumps and bounding could be prescribed as an alternative exercise for training the concentric function of the VASTUS.

Finally, the plantarflexors behave as net energy generators during running because of the large plantarflexion torque generated throughout stance (Schache et al., 2011). SOL and GLAT switched to net energy absorbers during the hurdle jumps and bounding, respectively. The change in SOL function during the hurdle jumps was the result of a moderate increase in total negative work. Compared to running, GLAT during bounding had a moderate increase in total negative work and a small increase in peak power absorption, while maintaining similar total positive work. Bounding involves long and leaping strides that exaggerate the horizontal and vertical displacement of the centre of mass. The greater negative work and power absorption during bounding is likely due to GLAT lengthening further at initial ground contact because of greater downwards momentum of the centre of mass. Thus, bounding may be useful for training the eccentric capacity of GLAT. Given that the hurdle jumps and bounding provided greater or similar mechanical work compared to running, these exercise may also have the potential for inducing adaptations in the mechanical and morphological properties of the triceps surae tendon among distance runners (Albracht & Arampatzis, 2013).

CONCLUSION: The biomechanical loads reported in this study can be used to guide exercise prescription and progressive overload during warm up protocols, training, or injury rehabilitation. Hurdle jumps may be an appropriate exercise when runners are seeking high eccentric loads of the GMAX. Hurdle jumps and bounding also had high plantarflexor loads compared to running. Distance runners may need to be cautious using these exercise within their warm up programs. The hurdle jumps and bounding had greater VASTUS total positive work compared to running and may be appropriate for training the concentric function of the VASTUS.

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