Lower Extremity Muscle Forces During Loaded Vertical Jumps and the Potential Training Implications

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Abstract

Hexagonal barbell (HB) loaded jumps are often used in training to increase lower extremity power. The effect of external load on lower extremity kinematics and kinetics during jumping has been described, but how individual muscles accommodate to these loads has not. Given the importance of coordinated muscular effort in achieving maximal power output, an understanding of how the lower extremity musculature individually performs during loaded jumps would be advantageous.

The purpose of this study is to describe the effect of load on individual muscle forces during the concentric phase of loaded HB jumps.

10 male collegiate athletes (20.4 ± 2.4 y; 108.8 ± 14.0 kg) performed 5 maximal HB jumps at 0%, 20%, 40% and 60% of their HB deadlift 1-repetition maximum (216.6 ± 10.9 kg). Filtered Ground reaction forces (300 Hz) and 3D lower extremity marker trajectories (13 Hz) were input into a 23 DOF musculoskeletal model and muscle forces were estimated with static optimization. Peak muscle force (xBW) was calculated for the gluteus maximum (GMAX), biceps femoris – long head (BFL), rectus femoris (RF), vastus intermedius (VAST), gastrocnemius (GAS), and soleus (SOL). Analysis of variance and LSD post hoc comparisons were used for analysis ($p < 0.05$).

A significant increase in peak muscle force across loads existed for VAST (0%: 7.89 ± 0.24 xBW; 20%: 8.22 ± 0.28 xBW; 40%: 8.47 ± 0.30 xBW; 60%: 8.64 ± 0.33 xBW), with significant differences between 0% and 40%, 0% and 60%, and 20% and 60% (all $p \leq 0.015$). Significant decreases were noted for RF (0%: 2.50 ± 0.13 xBW; 20%: 2.32 ± 0.17 xBW; 40%: 2.18 ± 0.11 xBW; 60%: 1.98 ± 0.20 xBW), with significant differences between 0% and all other conditions, and between 20% and 60% (all $p \leq 0.037$). Significant increases were found in GAS across loads (0%: 2.14 ± 0.10 xBW; 20%: 2.47 ± 0.14 xBW; 40%: 2.72 ± 0.12 xBW; 60%: 2.85 ± 0.14 xBW), with significance between each load (all $p \leq 0.038$). There was no significant difference in GMAX ($p = 0.325$), BFL ($p = 0.369$), or SOL ($p = 0.122$) across loads.

Increases in demand were not met with equally distributed increases in peak force output across the lower extremity musculature. The varied effect of load on force output from individual muscles is important information to understand when using loaded jumps as part of training for athletic performance.

Introduction

Vertical jumping is one expression of lower body power and is often used in training for the development of power [1]. To increase an explosive movement such as a vertical jump, practicing that motion is important to be able to best utilize increased muscular strength [3]. Jump squat training is a method of training where the vertical jump is loaded [2] in order to increase intensity of training, which allows for higher force generation and more power [1]. Although the strength of muscles determines the upper bound of muscle force and jump height, achieving peak height is heavily reliant upon optimal control, as preprogrammed stimulation patterns greatly affect the performance of explosive movements [3]. It is established that loading can affect the center of mass and thus can affect movement patterns [1], but how the load affects individual muscle forces during maximal effort jump squats remains unclear. The purpose of this study is to describe the individual muscle forces that occur during maximal unloaded vertical jumps and explore how those may change with increasing loads during the hexbar jump squat.

References

1. Swinton et al., J Strength Cond Res., 2012, **26**(4): p. 906-13.
2. Lockie et al., Strength Cond J., 2017, **39**(5): p. 24-32.
3. Bobbert et al., Med Sci Sports Exerc., 1994, **26**(8): p. 1012-20.

Methods

N = 10 (male, 20.4 ± 2.41 yrs). Subjects performing hexbar jump squats at 0%, 20%, 40%, and 60% of their hexbar deadlift 1RM. Positions of markers were captured at 200 Hz and filtered at 6 Hz, and ground reaction forces were captured at 1000 Hz and filtered at 300 Hz. The concentric phase of the jump was defined as the time from when the sacrum marker reached a vertical minimum to toe-off.

A 23 degree-of-freedom model was used, driven by 54 actuators. The lumbar, metatarsophalangeal (MTP), and subtalar joints were locked during simulations. Joint angles, joint moments, muscle forces, and muscle moments were calculated using OpenSim. Subject-specific scaling was performed using a static calibration trial, and four models were created for each subject to account for the mass of the hexbar. The maximal isometric force of all muscles was doubled. Joint angles were calculated using inverse kinematics (IK). Output trajectories from IK analysis were filtered at 13 Hz for all subsequent calculations. Joint moments were calculated using inverse dynamics. Individual muscle forces were calculated using static optimization.

Peak muscles forces during the defined concentric phase of each trial were calculated for the following muscles: gluteus maximus (GMAX), biceps femoris – long head (BFL), rectus femoris (RF), vastus intermedius (VAST), gastrocnemius – medial head (GAS), soleus (SOL). Peak muscle forces were calculated in both absolute terms and relative to body mass (xBW).

Significance was set a priori at $p < 0.05$. The dependent variables used for analysis were the mean relative peak muscle forces for GMAX, BFL, RF, VAST, GAS, and SOL within each condition, and the independent variable was load (control, 20%, 40%, 60%). RMANOVAs were performed to assess differences in relative peak muscle force across loads. Pair-wise comparisons with least significant difference were conducted when the RMANOVA was significant.

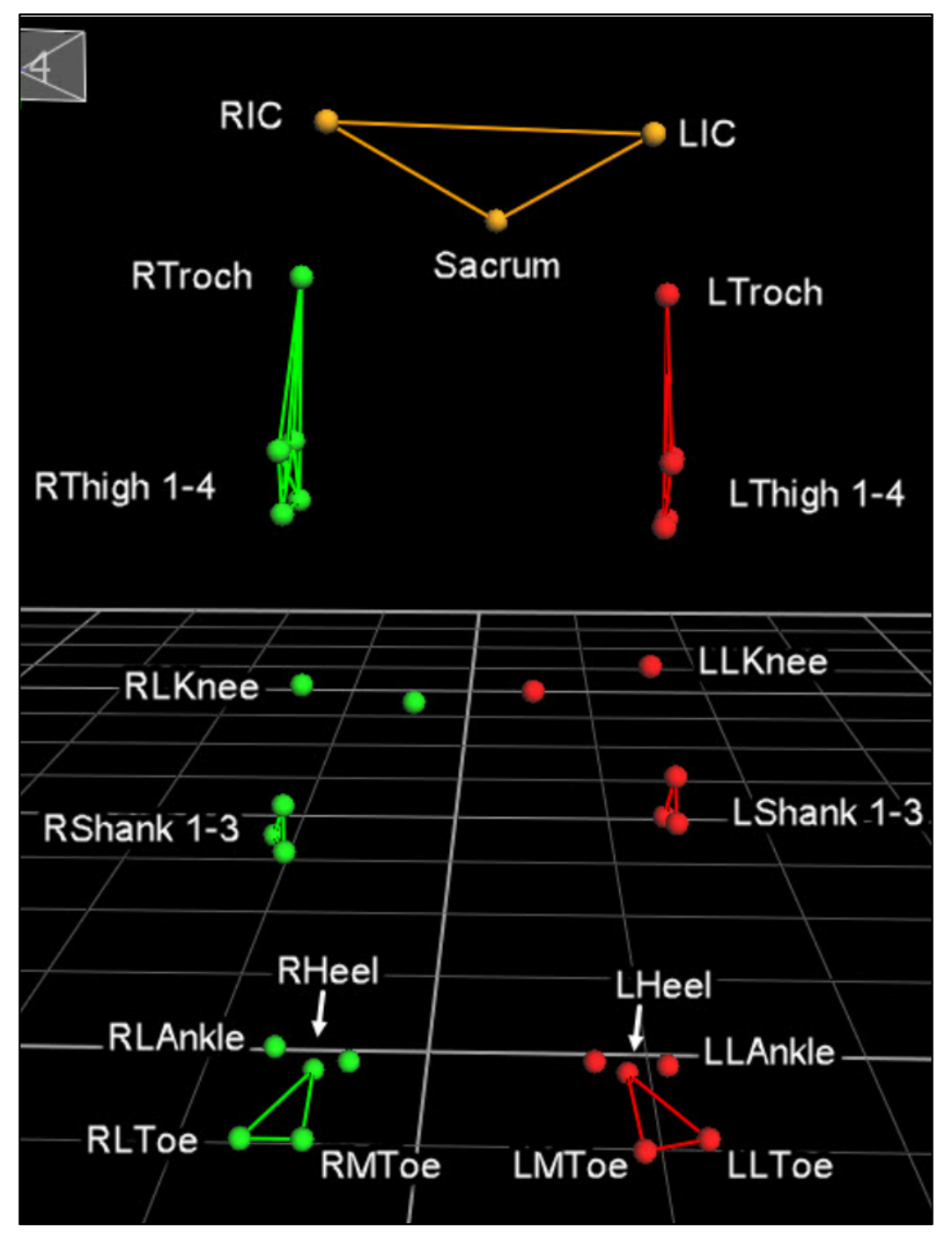


Figure 1. *Lower extremity marker set use for data collection*

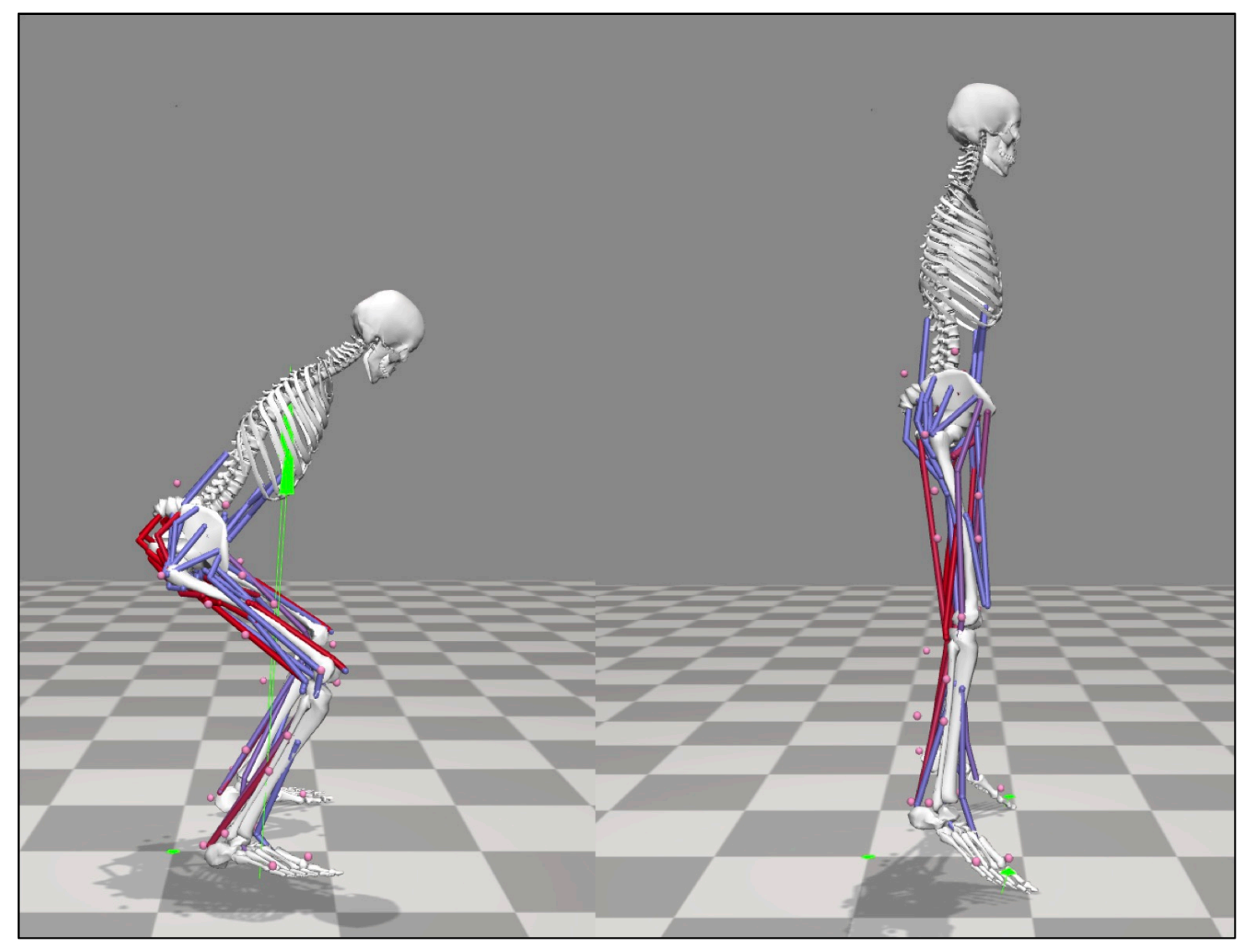


Figure 2. *Beginning (left) and ending (right) of the concentric phase*

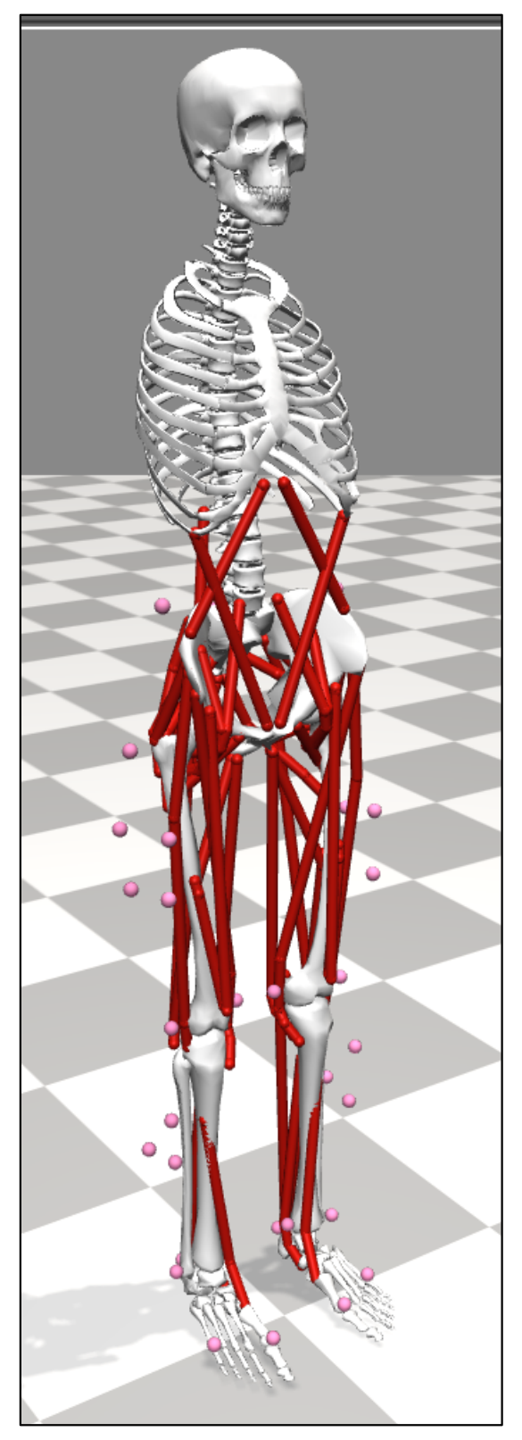


Figure 3. *Musculoskeletal model used for simulations*

Muscle		Load condition (%1RM) Control (0%)	20%	40%	60%
GMAX	Absolute	2719.19 ± 701.80	2753.98 ± 719.47	2810.52 ± 694.35	2557.80 ± 696.85
	Relative	2.53 ± 0.18	2.60 ± 0.20	2.62 ± 0.17	2.41 ± 0.18
VAST	Absolute	8352.92 ± 884.14	8656.59 ± 691.22	8927.62 ± 543.76	9087.16 ± 433.57
	Relative	7.89 ± 0.24 ^{c,d}	8.22 ± 0.28 ^{d}	8.47 ± 0.30 ^{a}	8.64 ± 0.33 ^{a,b}
GAS	Absolute	2262.16 ± 429.47	2613.43 ± 319.72	2862.31 ± 327.00	3015.59 ± 465.97
	Relative	2.14 ± 0.10 ^{b,c,d}	2.47 ± 0.14 ^{a,c,d}	2.72 ± 0.12 ^{a,b,d}	2.85 ± 0.14 ^{a,b,c}
SOL	Absolute	4137.77 ± 771.55	4267.82 ± 842.99	4323.66 ± 783.24	4518.91 ± 795.92
	Relative	3.89 ± 0.22	4.02 ± 0.19	4.05 ± 0.16	4.27 ± 0.18
RF	Absolute	2671.47 ± 528.48	2481.84 ± 697.95	2320.20 ± 490.38	2128.93 ± 738.50
	Relative	2.50 ± 0.13 ^{b,c,d}	2.32 ± 0.17 ^{a,d}	2.18 ± 0.11 ^{a}	1.98 ± 0.20 ^{a,b}
BFL	Absolute	3888.65 ± 417.41	3802.04 ± 307.20	3979.79 ± 528.88	3712.39 ± 628.25
	Relative	3.71 ± 0.21	3.61 ± 0.22	3.81 ± 0.27	3.56 ± 0.29

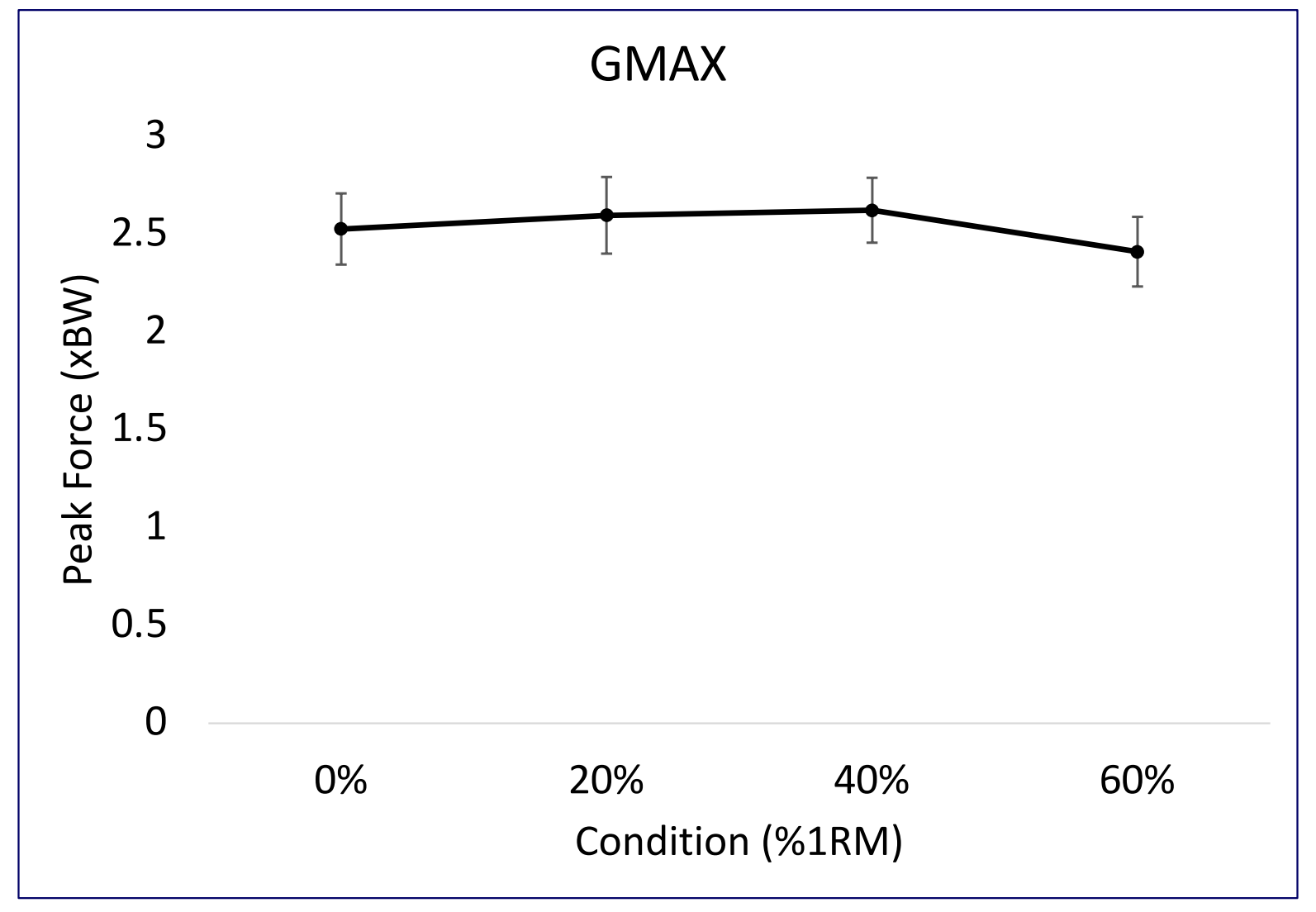
Table 1. *Absolute and Relative Peak Muscle Forces Across Loads*

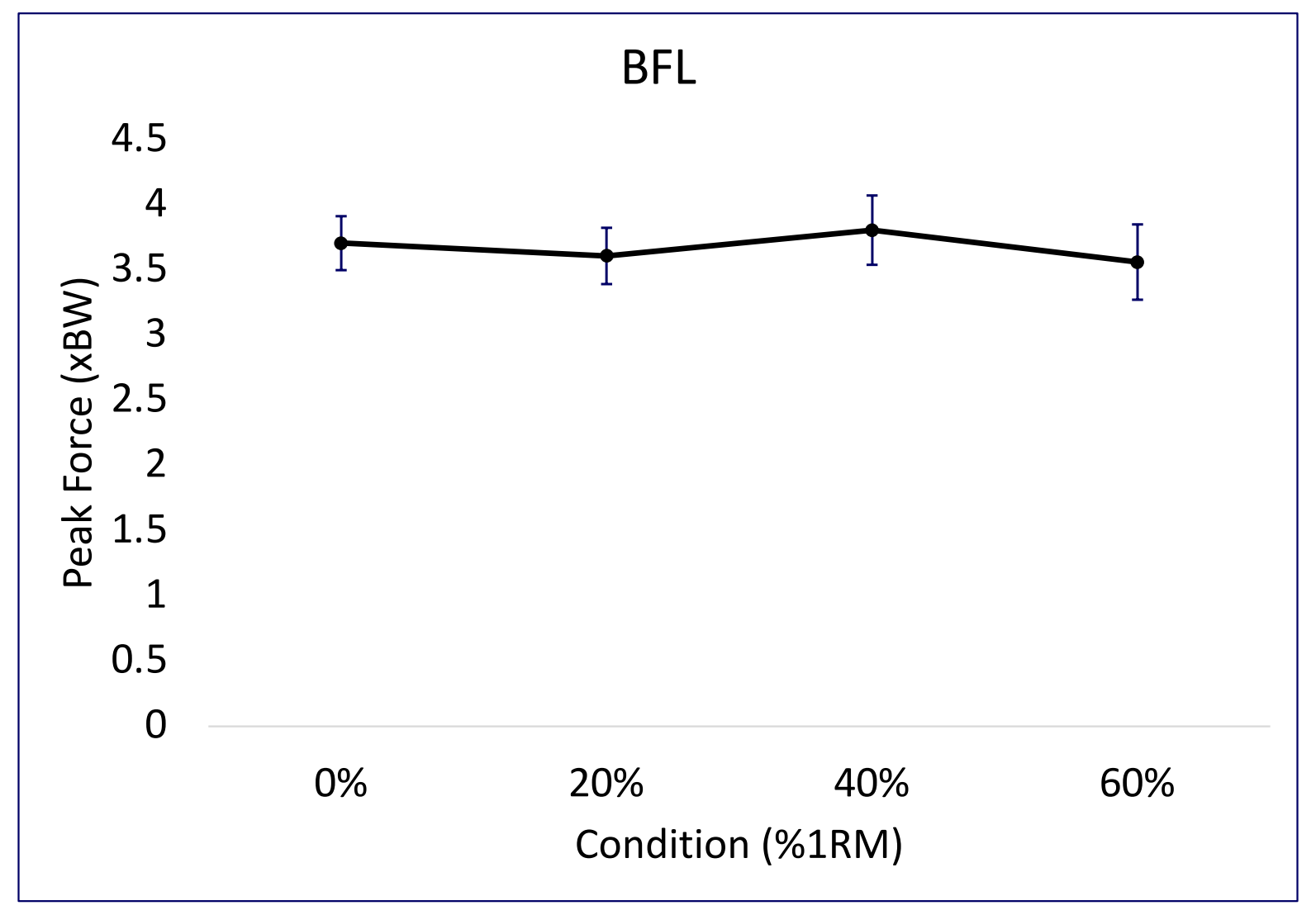
Notes: Absolute values are reported in N, relative values are normalized to body weight (xBW). Probability indicators are only listed for relative values, as statistics were only performed for relative values. Absolute values are presented for reference.

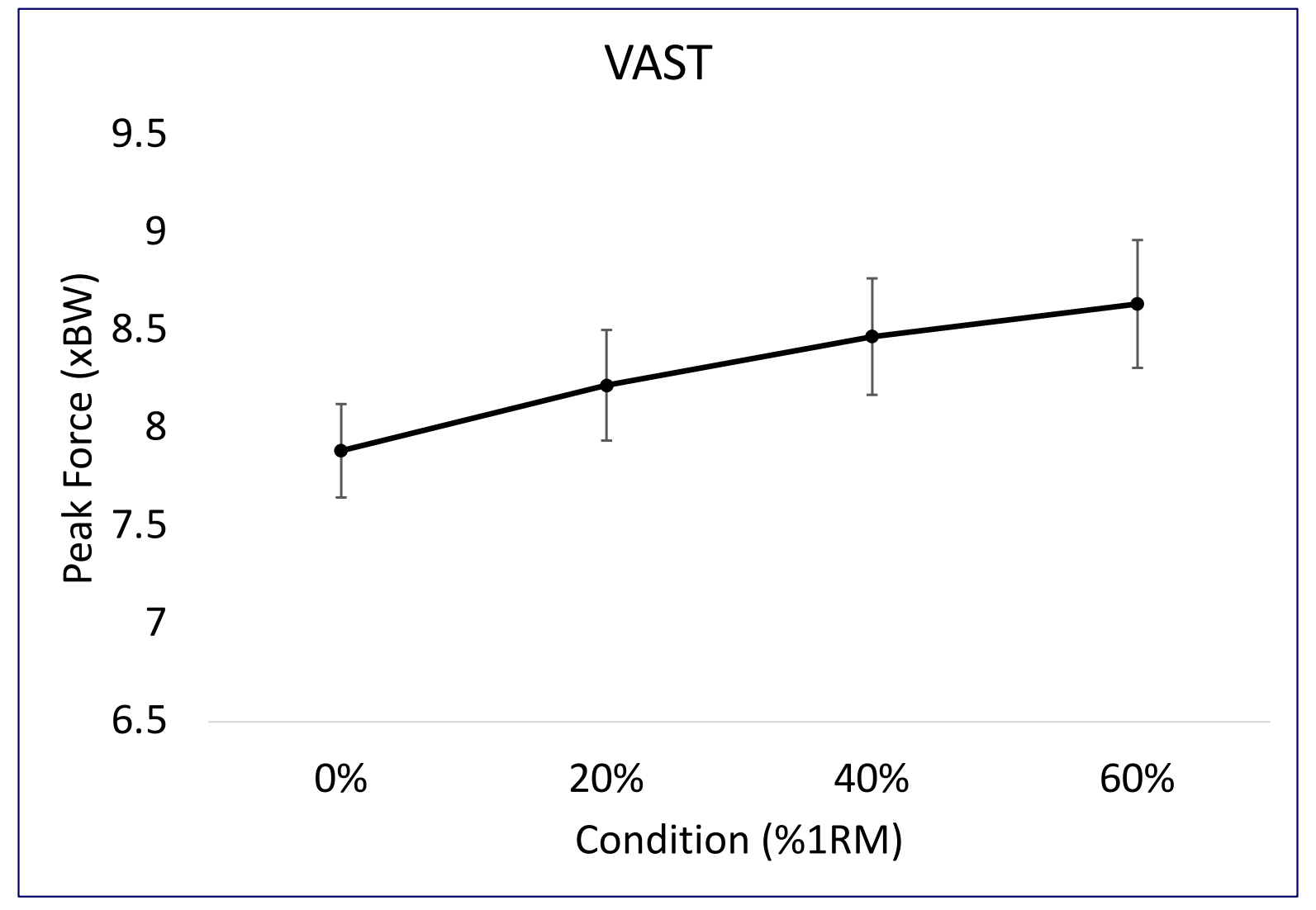
^{a}Denotes significant difference from control ($p < 0.05$); ^{b}Denotes significant difference from 20% ($p < 0.05$); ^{c}Denotes significant difference from 40% ($p < 0.05$); ^{d}Denotes significant difference from 60% ($p < 0.05$).

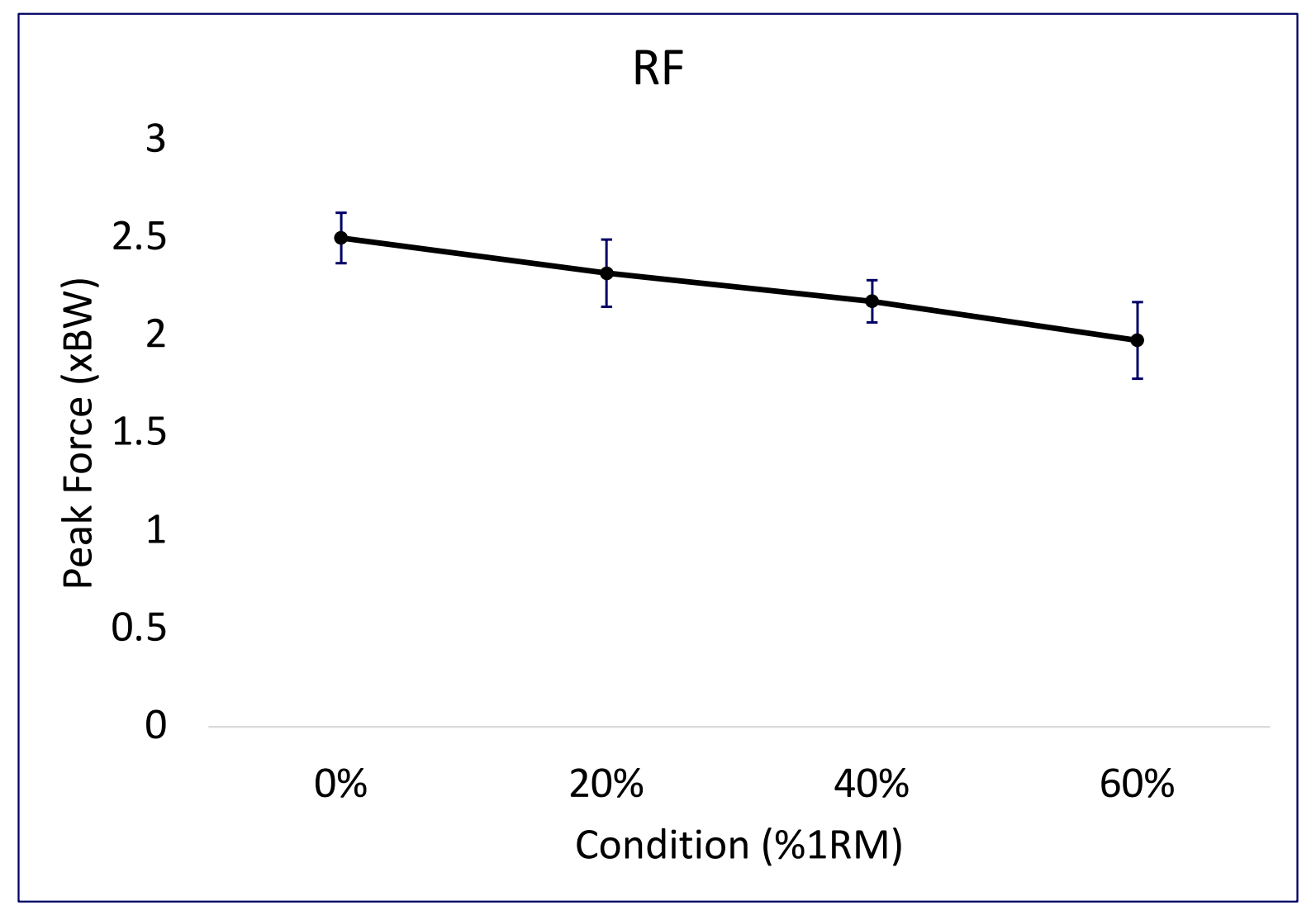
Results

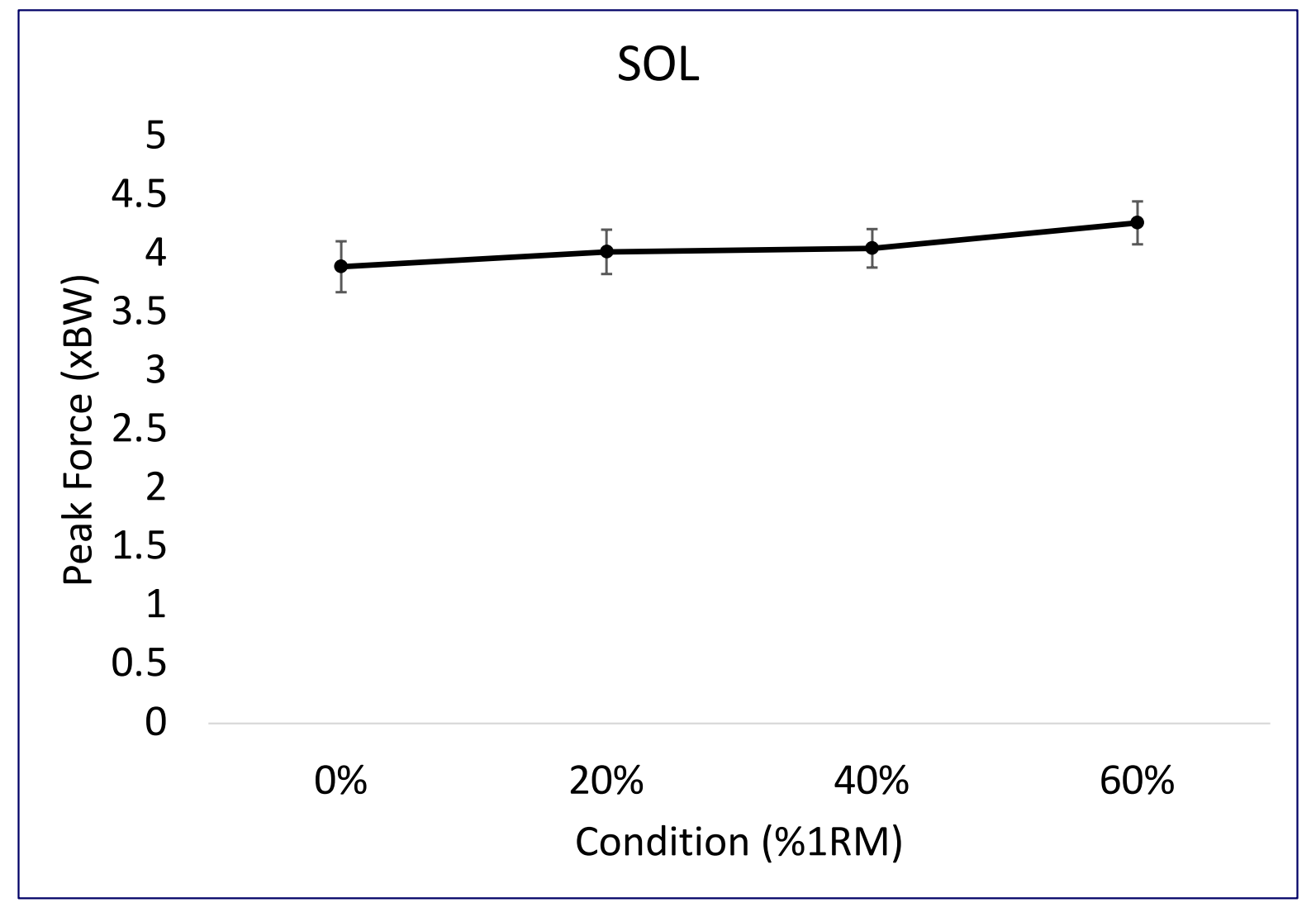
There were no significant differences in peak muscle force across loads for GMAX ($p = 0.325$; Table 1), BFL ($p = 0.369$; Table 1), or SOL ($p = 0.122$; Table 1). A significant increase in peak muscle force across loads existed for VAST ($p = 0.009$; Table 1), with significant differences between control and 40% ($p = 0.009$), control and 60% ($p = 0.015$), and 20% and 60% ($p = 0.011$). Significant decreases were noted for RF ($p = 0.017$; Table 1), with significant differences between control and 20% ($p = 0.034$), control and 40% ($p = 0.037$), control and 60% ($p = 0.005$), and 20% and 60% ($p = 0.032$). Lastly, GAS had significant differences across loads ($p < 0.001$; Table 1), with significant increases from control to each of the loaded conditions (all $p \leq 0.001$), between 20% and heavier conditions (all $p < 0.001$), and between 40% and 60% ($p = 0.038$).

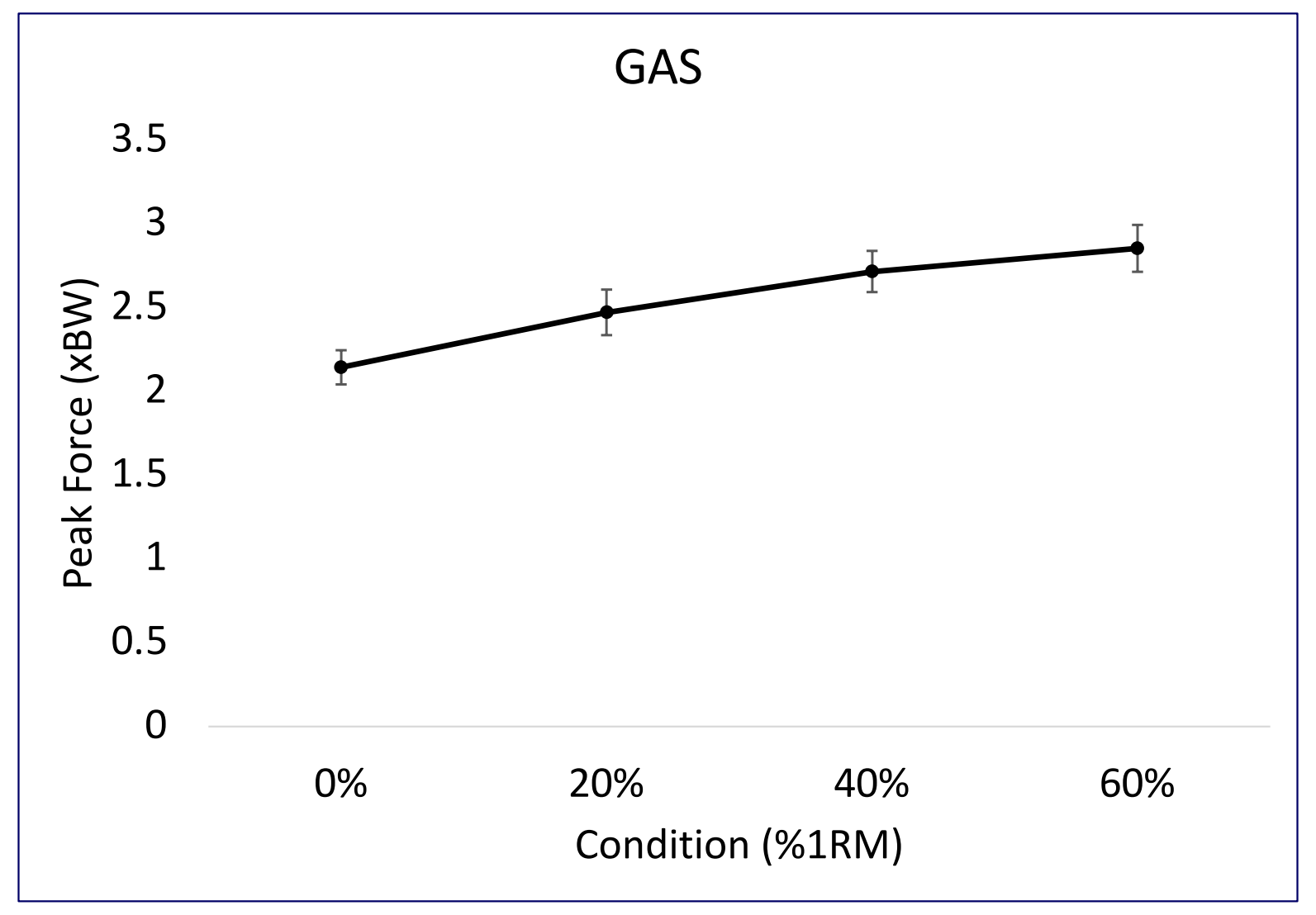












Conclusion

Individual muscle forces were estimated during maximal effort vertical jumps and hexbar jumps under loads up to 60% 1RM. Increases in demand were not met with equally distributed increases in peak force output across the lower extremity musculature. At the knee, uniarticular extensors increased peak force while biarticular extensors concomitantly decreased peak force. Biarticular ankle plantarflexors increased peak force, and hip extensors were unaffected by increases in external load. The varied effect of load on force output from individual muscles is important information to understand when using loaded jumps as part of training for athletic performance.