MUSCULAR CONTRIBUTIONS TO CENTER OF MASS ACCELERATION DURING COUNTERMOVEMENT JUMPS

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The purpose of this study was to study the contributions of individual leg muscles and muscle groups to accelerate the body's centre of mass (COM) during countermovement jumps (CMJ). Ten NCAA college basketball players performed maximal effort CMJ. Motion capture and ground reaction force data were recorded and used as inputs to a musculoskeletal model. The muscular contributions COM acceleration were quantified with three separate induced acceleration analyses (i.e., unit-force, maximum-force, and absolute-force analysis). All three analyses suggest that (in rank order of magnitude) the soleus, gastrocnemii, and vastii muscles exhibited the largest contributions to COM acceleration during CMJ.

KEY WORDS: biomechanics, sports, musculoskeletal modelling, induced acceleration analysis.

INTRODUCTION: The ability to jump as high as possible is purported to be an important determinant for success in several sports. For example, jumping is an integral aspect of high-level performance in basketball (McInnes, et al., 1995). A large portion of an athlete's physical conditioning therefore focuses on training the ability to jump higher (Montgomery, Pyne & Minahan, 2010). In order to optimize the effects of strength and conditioning sessions it would be valuable to know which muscles have the greatest potential to contribute to vertical jump performance.
Previous cross-sectional research has investigated the role and function of individual muscles and/or joints during jumping tasks (Bobbert et al., 1986; Kipp et al., 2017; Zajac, 1993). In addition, longitudinal and simulation studies have investigated the effects of specific training interventions on jump performance (Cheng, 2008; Nagano & Gerritsen, 2001). Little research, however, has attempted to identify the contributions of individual muscles to accelerate the body's COM during jumping tasks (e.g., Kipp et al., 2019). One approach to study the muscular contributions to COM acceleration during given tasks is to use musculoskeletal modeling. For example, induced acceleration analysis (IAA) decomposes the contribution of each muscle towards the body's COM acceleration in any given direction (Zajac, 2002). In addition, certain types of IAA can be used to assess the potential for muscles to contribute to COM acceleration while also accounting for force-length-velocity properties and capacities of the respective muscles (Correa & Pandy, 2013; Goldberg & Kepple, 2009).
The purpose of this study was to study the contributions of individual leg muscles to COM accelerations during countermovement jumps (CMJ). The overall goal of this research is to identify muscle-specific contributions to maximal dynamic perfomance of jumping tasks to improve the design of strength and conditioning sessions for athletes.

METHODS: Five male (height: 1.84±0.14 m; mass: 92.8±11.4 kg) and five female (height: 1.71±0.09 m; mass: 80.1±17.6 kg) NCAA Division I basketball players participated in this study. All players provided written informed consent, which was approved by Marquette University's IRB. Each player performed three maximal effort CMJ without arm swing (i.e., hands were held at the waist). Kinematic and kinetic data were collected during each CMJ. Kinematic data were collected with a 14-camera motion capture system at 100 Hz. Kinematic data were recorded from reflective markers that were attached to various anatomical landmarks and marker clusters that were attached bi-laterally to the thighs, shanks, and feet. Kinetic data were collected at 1000 Hz from two force plates.
Marker data from static trials were used to scale a musculoskeletal model to each subject through modification of model parameters (e.g., bone length) (Figure 1A) (Catelli et al., 2019). This model was specifically developed for motions with large hip and knee flexion

ranges of motion and uses special wrapping surfaces to enable the analysis of moment arms and muscle lenghts during motions with up to 138° of hip flexion and 145° of knee flexion.
Joint angles were calculated with an inverse kinematics approach and a residual reduction algorithm was used to minimize residual forces and moments (Figure 1B & 1C). Muscle forces were calculated with the computed muscle control algorithm (Figure 1D). The potential contributions of each muscle to the vertical acceleration of the COM were calculated with three separate IAA (Figure 1E) (Correa & Pandy, 2013; Goldberg & Kepple, 2009).

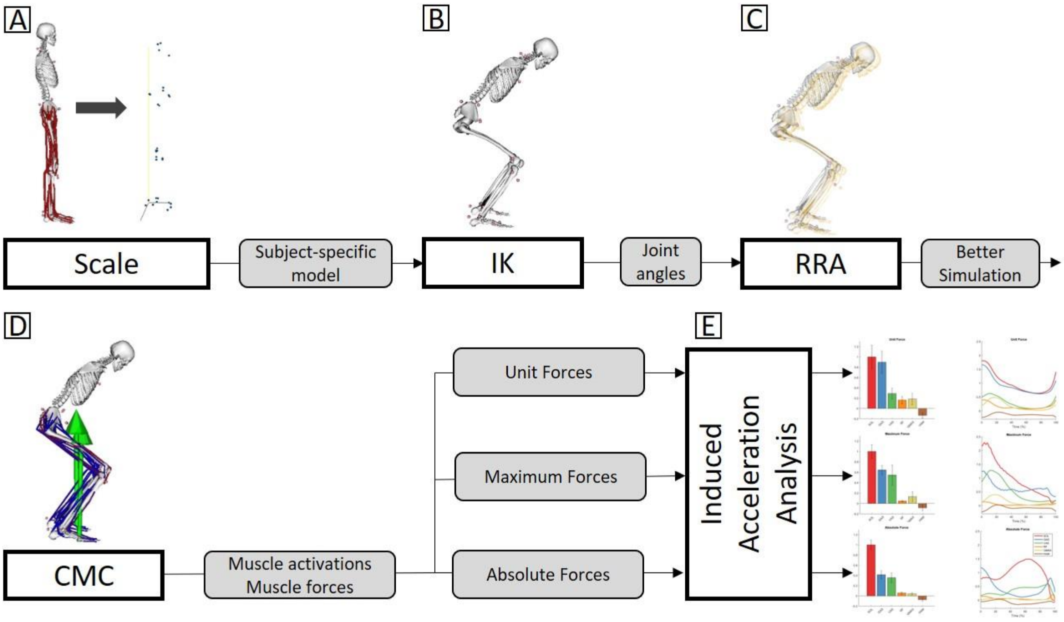

Figure 1: Depiction of the workflow for the induced acceleration analyses.

The first IAA (i.e., unit-force analysis) used a perturbation analysis to calculate the potential accelerations of the COM due to a 1 N increase in force of each respective muscle or muscle group under investigation. These perturbations were performed at each time point of the CMJ movement phase to investigate the pattern of potential contributions of each muscle to accelerate the COM in the vertical direction during CMJ. Data from the unit-force analysis thus provides insight into the capacity of each muscle to accelerate the COM if all muscles were activated equally. The second IAA (i.e., maximum-force analysis) multiplied the unit-force IAA with each muscle's theoretical maximum force, which accounted for the muscle-tendon unit's force-generating properties. The product of this multiplication thus provides insight into the capacity of each muscle to accelerate the COM if it were maximally activated. For the third IAA (i.e., absolute-force analysis), the unit-force IAA were multiplied with the muscle forces that were estimated with the computed muscle control algorithm and thus represent the contributions to vertical acceleration of the COM during the CMJ as estimated in the actual study.
The potential contributions of all muscles to COM accelerations were grouped as GMAX (superior, medial, and inferior fibers of gluteus maximus), HAM (semitendinosus, semimembranosus, and biceps femoris long head), VAS (vastus lateralis, medialis, and intermedius), RF (rectus femoris), GAS (medial and lateral gastrocnemius), SOL (soleus), and time-normalized across the movement phase of the CMJ. The movement phase was defined as the time interval between when the vertical GRF fell below 95% of body-weight and when the feet left the ground (i.e., GRF < 10N). The contributions of individual muscles and muscle groups to COM acceleration during this phase were then examined (Figure 2). In order to compare the potential accelerations calculated with each type of IAA, the contributions from each muscle were normalized to the largest positive mean acceleration (Correa & Pandy, 2013).

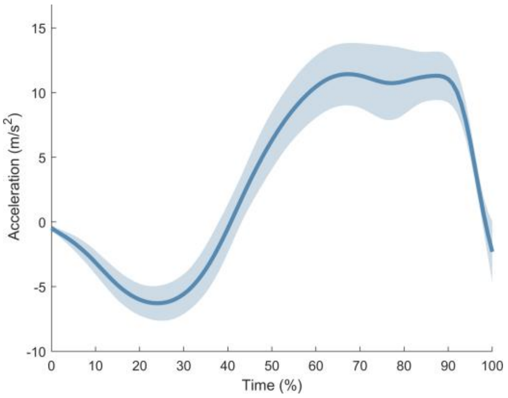

Figure 2: Vertical acceleration (mean±SD) of the centre of mass during the countermovement jump phase.

RESULTS: The rank order of the potential of each muscle to contribute to the vertical acceleration of the COM during CMJ were similar among all three induced acceleration analyses (Figure 3). Notably, within each IAA the soleus, gastrocnemii, and vastii muscles exhibited the largest contribution to vertical COM acceleration during the CMJ.

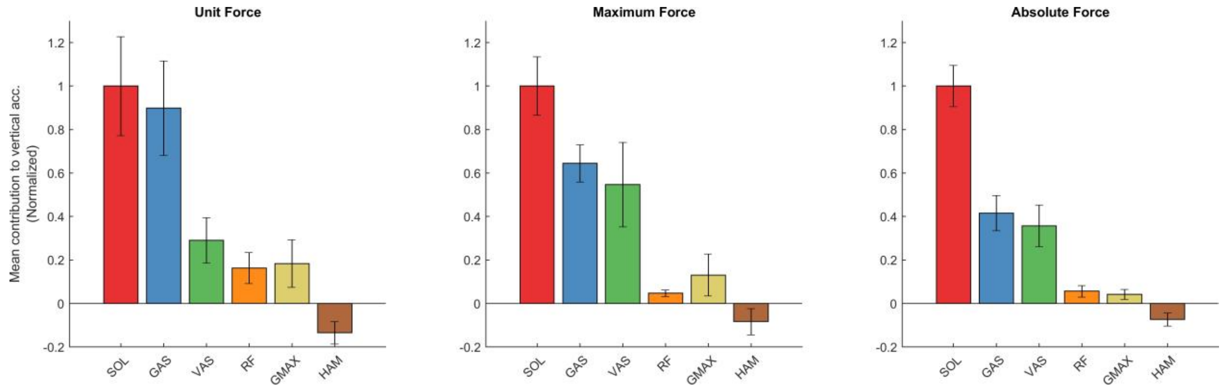

Figure 3: Normalised muscle contributions (mean±SD) to vertical acceleration of the centre of mass with the unit-force (left), maximum-force (middle), and absolute-force (right) method across the entire countermovement jump phase.

DISCUSSION: The purpose of this study was to study the contributions of individual leg muscles to COM accelerations during countermovement jumps (CMJ). The three types of IAA all suggest that the soleus, gastrocnemii, and vastii muscles exhibited the largest contribution to accelerate the COM in the vertical direction during CMJ. With respect to the magnitude of the contributions from each of the three muscles, the results suggest that vertical acceleration of the COM is primarily the result of force production from the SOL muscle, and to a lesser extent from the gastrocnemii and vastii muscles. It is interesting, to reconcile these findings with other research that has pointed to the importance of hip mechanics in relation to CMJ performance (Vanezis & Lees, 2005). It could be that this discrepancy is due to the differences in populations between studies. For example, it may be that basketball players perform CMJ with a more vertical torso position, which would decrease the demand on the hip extensor musculature (Vanrenterghem et al., 2008).

Comparisons among the three IAA analyses highlight two interesting findings. First, there is a considerable difference between the contributions to vertical COM acceleration from the unit-force and maximum-force IAA for the gastrocnemii and the vastii muscle groups. These differences likely reflect the fact that the maximum-force IAA accounts for the size of the respective muscles and their force-length-velocity properties, whereas the unit-force analysis does not (Correa & Pandy, 2013). Second, there is a much closer agreement between the contributions to vertical COM acceleration from the maximum-force and absolute-force IAA for all muscles. While both of these IAA account for the muscle's force-length-velocity properties, this agreement also likely indicates that the CMC optimisation selected the appropriate muscle (i.e., those with high potential to accelerate the COM) (Correa & Pandy, 2013). The implication of this latter finding may also indicate that the gastrocnemii and vastii muscles are not operating near their predicted maximum capacity as evidenced by the lower potential contribution to vertical acceleration during the absolute-force IAA. Although based on a bit of speculation, this assertion is corroborated by computational studies where simulated strength training of the knee extensor muscles leads to an increase in CMJ height.

CONCLUSION: This study identified the contributions of individual muscles to vertical COM accelerations during CMJ in male and female basketball players. The practical implications of these results suggest that vertical acceleration of the COM in this population of athletes is driven by the soleus, gastrocnemii, and vastii muscles. Furthermore, the results may suggest that the gastrocnemii and vastii muscle groups are not operating near their maximum capacity. Future studies, however, should investigate this assertion in more detail.

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ACKNOWLEDGEMENTS: The authors would like to thank the Marquette University Sports Performance staff for their collaboration with this project.