MUSCLE FORCE CONTRIBUTIONS TO GROUND REACTION FORCE PROFILES DURING BASKETBALL RELATED TASKS

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The purpose of this study was to describe the contributions of individual leg muscles to the production of ground reaction forces (GRF) during basketball related tasks. One male and female college basketball player performed horizontal drop vertical jumps (DJ) and lateral side steps (SS). Motion capture and GRF data were recorded and used as inputs to an induced acceleration analysis to calculate the contribution of each muscle to the GRF during each task. Soleus and vasti muscle forces were the respective primary and secondary contributors to vertical GRF during the DJ. Forces from the vasti muscle group were also the primary contributor to posterior braking GRF during the DJ. Medial GRF during the SS were primarily the result of vasti and soleus muscle forces. Muscle force contributions to GRF did not differ markedly between players.

KEY WORDS: biomechanics, sports, musculoskeletal modelling, OpenSim, coordination.

INTRODUCTION: Basketball is a physically demanding sport that requires players to perform a combination of running, jumping, and cutting tasks (Abdelkrim, El Fazaa & El Ati, 2007; McInnes, et al., 1995). In particular, executing jumping and lateral movement tasks as fast as possible (i.e., with high muscular effort) is an integral aspect to high-level performance in basketball (McInnes, et al., 1995). It is for this reason that a large portion of a basketball player's physical conditioning focuses on training their ability to jump higher and move faster (Montgomery, Pyne & Minahan, 2010). In order to optimize the effects of these physical conditioning sessions it would be valuable to know which muscles contribute most to the performance of specific basketball related tasks (e.g., vertical jump).
Researchers have investigated activation patterns of individual muscles during athletic tasks in order to understand muscle-specific contributions to performance outcomes of these tasks (Besier, Lloyd & Ackland, 2003; Neptune, Wright & Van Den Bogert, 1999). It is, however, not easy to fully appreciate and ascribe whole-body performance outcomes to the contributions of individual muscles because of the mechanical complexity of multi-joint systems (Zajac & Gordon, 1989). Muscles forces interact dynamically with gravitational and inertial forces during coordinated movement of the musculoskeletal system (Zajac & Gordon, 1989). Moreover, activation of individual muscles may also affect the mechanics at other joints via inter-segmental dynamics or coupling (Zajac & Gordon, 1989).
One approach to address these issues is to use musculoskeletal modeling to determine the contributions of individual muscles to the acceleration of the body's centre-of-mass (COM) (Neptune, Kautz & Zajac, 2001; Zajac, 2002). This approach, also referred to as induced acceleration analysis (IAA), accounts for gravitational and inertial forces and decomposes the influence of each muscle towards the body's COM acceleration in the horizontal and vertical directions. Similarly, IAA can also be used to determine muscular contributions to the production of horizontal and vertical ground reaction forces (GRF) during athletic tasks (Dorn, Schache & Pandy, 2012; Maniar et al., 2019). The purpose of this study was to use an IAA approach to describe the contributions of individual leg muscles to the production of GRF during basketball related tasks. The overall goal of this research is to identify muscle-specific contributions to perfomance outcomes of jumping and cutting tasks to improve the design of physical conditioning and training sessions of basketball players.

METHODS: One male and one female NCAA Division I basketball player were recruited for this study. Each player provided written informed consent, which was approved by the local University's IRB. Each player performed three horizontal drop vertical jumps (DJ) and three lateral defensive slides to his/her right side (SS). For the DJ, players jumped forward off a 30.5 cm box and performed a maximal vertical jump. The horizontal jump distance was normalized to 50% of each players body height. For the SS, each player got into his/her defensive position and performed three lateral slides to the right side (i.e., off the left leg) as fast as possible. Kinematic and kinetic data were collected during each DJ and SS. Kinematic data were collected with a 14-camera motion capture system at 100 Hz (T-Series Cameras, Vicon Denver, Centennial, CO, USA). Kinematic data were recorded from 30 reflective markers that were attached to various anatomical landmarks and marker clusters that were attached bi-laterally to the thighs, shanks, and feet (Figure 1). Kinetic data were collected at 1000 Hz from two force plates built into the floor (Models OR6-6, Advanced Mechanical Technologies Inc., Watertown, MA, USA).

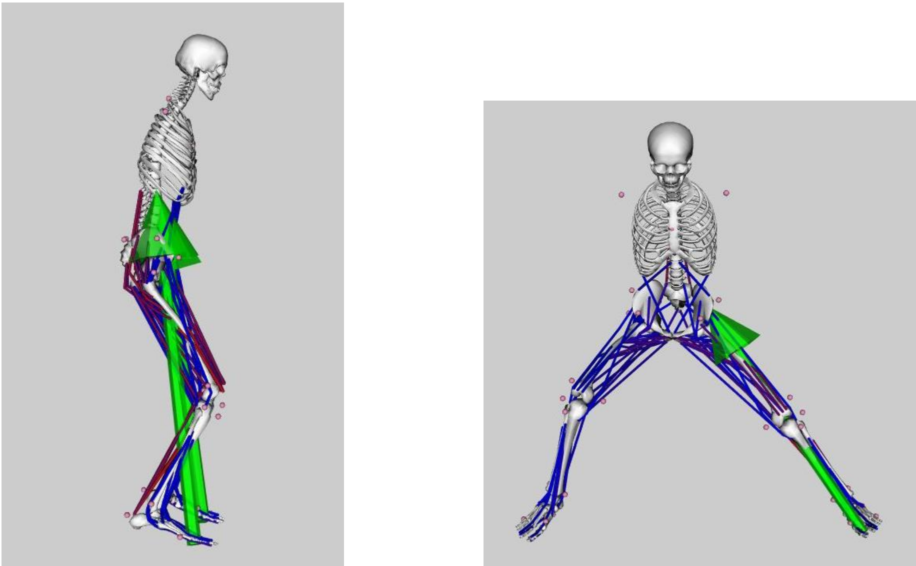

Figure 1: Depiction of the Gait2392 Model during the DJ (left) and SS (right).

Joint angles, muscle forces, and muscle contributions to COM acceleration were calculated with OpenSim (Delp et al., 2007). The Gait2392 Model was scaled with static trials of both subjects to represent each subject through modifying model parameters (e.g., bone size or muscle resting length). Inverse Kinematics were used to calculate joint angles. The joint angles and GRF were used as input to Static Optimization, which calculates muscle forces that reproduce the model kinematics (i.e., joint angles) and kinetics (i.e., GRF) with a cost function (minimizing squared activations). Then, IAA computed COM accelerations induced by each muscle (Hamner & Delp, 2013). The contributions of muscles were grouped as GMAX (anterior, medial, and posterior fibers of gluteus maximus), HAMS (semitendinosus, semimembranosus, and biceps femoris long head), VAS (vastus lateralis, medialis, and intermedius), RF (rectus femoris), GAS (medial and lateral gastrocnemius), SOL (soleus), and GMED (anterior, medial, and posterior fibers of gluteus medius) and time-normalized across stance phase (i.e., contact with the force plate).

RESULTS: The GRF profiles during the DJ were characterised by vertically- and posteriorly-directed GRF (Figure 2). Vertical GRF were produced primarily by force contributions of the SOL and VAS muscles throughout the stance phase. In addition, the GAS muscle contributed to the GRF during the latter part of the stance phase. Interestingly, the GRF profile of the male athlete were characterised by a more marked impact transient that appeared to arise from force production of the GMAX and HAMS muscles. Posterior GRF were produced primarily by force contributions of the VAS muscles throughout the stance phase (Figure 2). In contrast, the SOL muscles created an anterior GRF. In addition, the male athlete also exhibited an anteriorly-directed force contribution from the HAMS muscle.
The GRF profiles during the SS were characterised by marked medially-directed GRF (Figure 3). Medial GRF throughout stance were produced primarily by force contributions

from the SOL and VAS muscles. In addition, the GAS muscle force production also contributed to the medial GRF during the last 20% of stance.

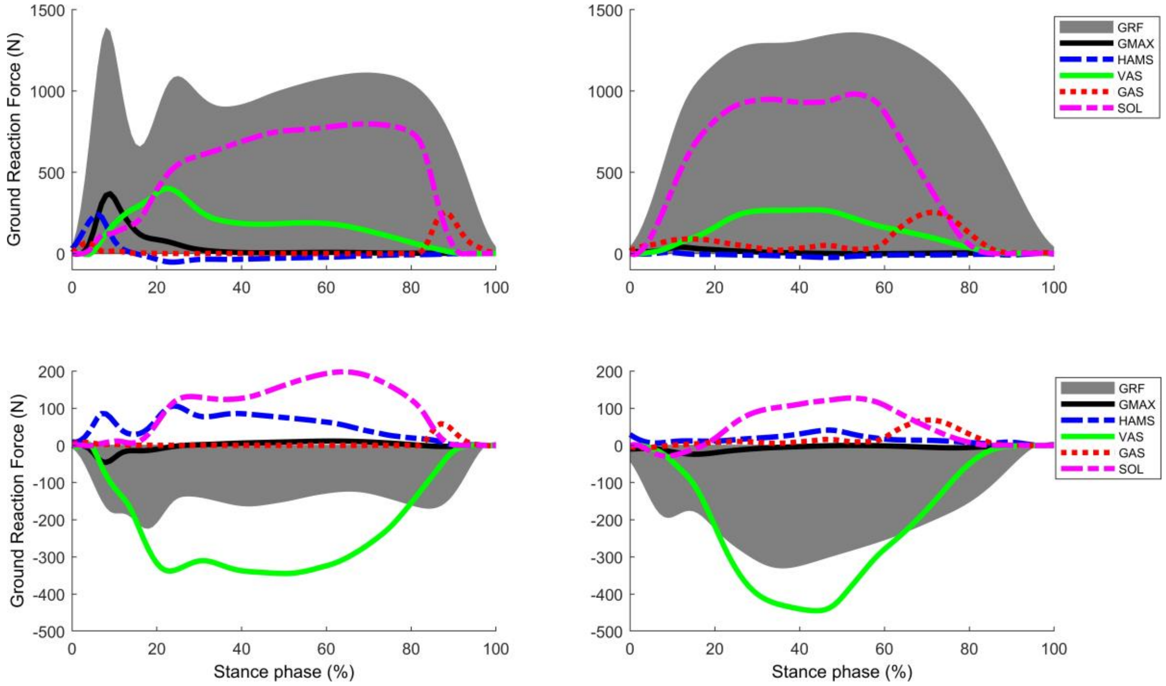

Figure 2: Vertical (top row) and horizontal (bottom row) GRF profiles (shaded grey area) and the contributions of all individual muscles (colored lines) during the DJ for the male (left column) and female (right column) basketball player.

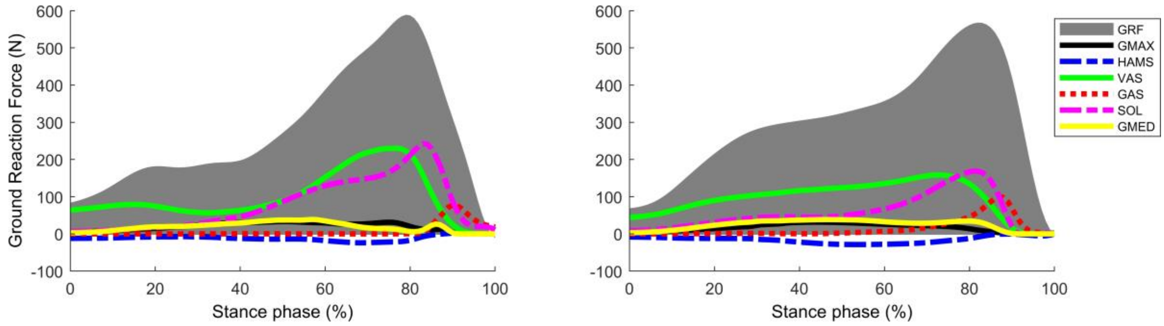

Figure 3: Lateral GRF profiles (shaded grey area) and the contributions of individual muscles (colored lines) during the SS for the male (left column) and female (right column) basketball player.

DISCUSSION: The purpose of this study was to describe the contributions of individual leg muscles to the production of GRF during basketball related tasks. IAA was able to show the contributions of individual muscles to the acceleration of the COM, and hence the GRF. The results suggest that vertical GRF during the DJ were primarily the result of force production from the SOL and VAS muscles. The GAS muscles also contributed to the vertical GRF, but only towards latter 20% of the stance phase. These findings are similar to those reported for side-cutting, where the SOL, VAS, and GAS were the primary contributors to the generation of vertical GRF (Maniar et al., 2019). Noticeable muscle force contribution from the GMAX and HAMS only appeared to be present in the male athlete, and only during the initial impact phase (5-15%) of stance.

While the VAS muscles did contribute to the vertical GRF during the DJ, these muscles contributed relatively more to the production of the posteriorly-directed (i.e., horizontal braking) forces. The VAS muscles therefore seemed to play a much larger role in controlling the deceleration of the COM during the DJ rather than acceleration in the vertical direction. It is also interesting to note that the HAMS muscle group contributed to forward acceleration of the body's COM, but only for the male athlete. Opposing contributions of the VAS and SOL,

and to some extent HAMS in the male athlete, to the anterior/posterior GRF profile have also been reported previously for side-cutting (Maniar et al., 2019).
For the SS, force production from the SOL and VAS muscle groups were the largest contributors to the production of medially-directed GRF. It is surprising to note that the GMED did not contribute noticeably to the production of GRF in the medial direction. Collectively, these results indicate that sagittal plane muscles are more important to lateral movement performance than frontal plane muscles. The implication of this finding is quite significant with respect to designing training programs for basketball players.

CONCLUSION: In summary, this study highlighted the contributions of individual muscles to the production of GRF during basketball related tasks. The practical implications of these results suggest specialized roles for muscles in the production of task-specific vertical, horizontal, and medial GRF. Therefore, future studies should investigate the effects of selectively training these muscles to improve performance in basketball related tasks.

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