Supraspinatus Produces Highest Muscle Force as Glenohumeral Joint Force Increases with Speed

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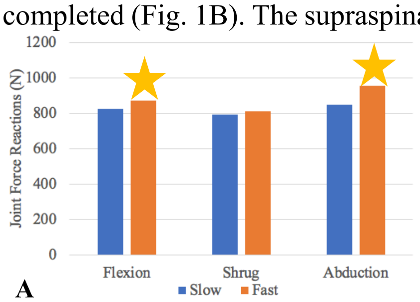
Introduction: Shoulder injuries account for 8-25% of all volleyball-related injuries [1] with 80% of shoulder pain linked to the repetitive spiking movement [2]. These injuries are among the leading causes of time lost from training and competition among female volleyball players [1]. Understanding the forces exerted by the joints and muscles during this movement may lead to patient-specific treatments. The average speed of a collegiate spike is about 50 mph [3]. The glenohumeral joint, which is stabilized by the rotator cuff, plays a major role in producing the forces that allow the shoulder to perform these spiking motions. The rotator cuff consists of four major muscles: supraspinatus, infraspinatus, teres minor, and subscapularis. The two main goals of this study were to (1) determine how speeds can affect the joint forces at the glenohumeral joint and (2) identify which rotator cuff muscles are dominant during various shoulder movements (flexion, abduction, and shrug). *We hypothesized the joint force would increase (>5%) with speed due to the high forces needed to produce the quick motion. The infraspinatus was hypothesized to be the dominant muscle of the rotator cuff during spiking, as its primary role is external rotation.*

Materials and Methods: The scapulothoracic shoulder model developed in OpenSim 4.0, which includes all of the rotator cuff muscles, was used for this study [4]. Three motions (flexion, abduction, and shrug) provided with the model were simulated at two different speeds (slow vs. fast). For the fast simulations, the time columns were edited in Excel by decreasing the original increments of time; this doubled the speed of the fast motions (i.e. 7.93s to 3.965s) . The Computed Muscle Control (CMC) tool was used to identify muscle excitation levels by determining a combination of proportional-derivative controls and static optimizations (initial states). These controls and initial states were then used as the input for the Forward Dynamics tool to determine the muscle actuators of the rotator cuff. The Joint Reaction Analysis tool computes resultant forces at a joint by calculating the joint forces and moments transferred between consecutive bodies as a result of all loads acting on the model. This tool was used to analyze the joint forces at the glenohumeral joint. OpenSim recorded the joint forces as three dimensional vectors with components in each plane (fx, fy, and fz). To enable comparison to previous studies, the Euclidean norm of the glenohumeral joint force was calculated to determine total force magnitude.

Results and Discussion: An increase in misdirected joint force may create instability at the glenohumeral joint resulting in a rotator cuff injury. Although spiking is a complex motion that was not directly simulated in this study, during a simple abduction motion, the glenohumeral joint force increased by 12.8% between the slow and fast conditions (Fig. 1A). This result supports the idea that a spike increases joint forces, potentially placing the muscles at risk of injury. Further investigation examining dominant muscle forces during slow and fast motions was also completed (Fig. 1B). The supraspinatus produced the largest muscle force during fast abduction motions (281.2 N).



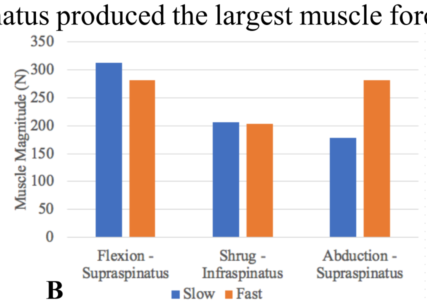


Figure 1. (A.) Joint forces at the glenohumeral joint. Forces that increased by greater than 5% indicated with a star. (B) Muscle forces from the rotator cuff muscles that produced the greatest forces for each of the three motions.

Conclusions: Through this simulation study it has been demonstrated that an increase in speed results in increased glenohumeral joint forces. Increasing the speeds of motions may lead to instability of the shoulder, however, the rotator cuff muscles have the ability to stabilize the glenohumeral joint. The supraspinatus muscle produced the most force for the flexion and abduction motion. Further studies on the role of the supraspinatus during the high speeds of volleyball spikes will lead to a better understanding of how rehabilitation treatments can improve muscle strength and mitigate the effects of rotator cuff injury.

References: [1] Reeser et al. (2006) *Br J Sports Med.* 40(7):594-600 [2] Shih et al. (2019) *J Athl Train* 54(1): 90–98 [3] Shea, J (2013) *SportRec* [4] Seth et al. (2019) *Front. Neurorobot*. 13:90