DEVELOPMENT OF A BIOMECHANICAL SHOULDER MODEL FOR ERGONOMIC ANALYSES

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INTRODUCTION

The study of work-related shoulder disorders has recently elicited an increased amount of attention by scientists [1]. Indeed, load levels in shoulder tissues have been identified as a risk factor for the development of these musculoskeletal disorders [2]. Despite this, few tools are available for the assessment of loading of shoulder structures for dynamic work tasks, especially in prospective job design. Thus, a computerized biomechanical model of the shoulder was developed. There are three major modules in the model: 1) a shoulder geometry module; 2) a dynamic torque module; and 3) a muscle force prediction module. The modules were evaluated empirically with a set of load transfer tasks.

METHODS

The most critical design criterion for the modules was future implementation in prospective job analysis tools, including digital human modeling (DHM) software. Hence, the modules are driven by data types producible in virtual environments: body landmark motion, task and anthropometric properties.

Several aspects of the geometric model were based on prior findings [3,4], including segment and muscle unit definitions, placements of muscle attachment sites, and a mathematical shoulder rhythm. A graphical representation of the internal musculature was developed (Figure 1), allowing visualization of the movements of the shoulder components during motion.

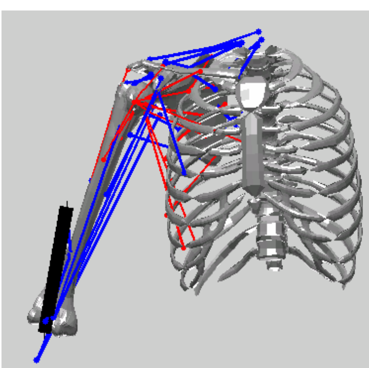

Figure 1: Internal Shoulder geometry. Muscles are shown as having linear and wrapped lines of action.

The external torque module requires 3-D dynamic equilibrium about each of the three joints in the upper arm (wrist, elbow, and glenohumeral), and generates 3-D shoulder joint torques. These torques are inputs to the internal force prediction module. This module distributes these torques amongst 38 muscle units through use of an optimization paradigm. The model includes a novel glenohumeral constraint based on empirical data [5].

Additionally, load transfer tasks were performed by 8 subjects. The tasks were one-handed transfers of loads to locations in the right-handed reach envelope. Hand Loads were varied between 0 and 50% of extended arm flexion/abduction strength. Surface Electromyography (sEMG) data was collected for 11 shoulder muscles to enable model evaluation.

RESULTS AND DISCUSSION

The model showed differential ability across muscles to predict the levels of activation demonstrated by the sEMG recordings as shown by the correlation coefficients in Table 1. Concordance analysis also showed higher concordance ratios for muscles that were primary agonists.

Table 1. Correlation coefficients of predicted and recorded muscle forces levels in the shoulder.

Muscle	*r* value
Infraspinatus	0.63
Biceps	0.61
Deltoid, Total	0.53
Lower Trapezius	0.52
Middle Deltoid	0.42
Latissimus Dorsi	0.32
Posterior Deltoid	0.31
Trapezius, Total	0.27
Anterior Deltoid	0.26
Upper Trapezius	0.01
Pectoralis Major	0
Triceps	-0.20

CONCLUSIONS

The model showed the highest predictive performance for those muscles that were demonstratively most active by sEMG recordings. Muscles that were not mechanical contributors to resisting the calculated external shoulder torques were predicted less accurately. These results are likely due to the combination of the use of a monotonically increasing cost function in the optimization (muscle stress cubed), and the exclusion of potential confounding factors (i.e. segment stiffness, detailed muscle properties). Nonetheless, from an ergonomic analysis point of view, the model is useful for identifying those tissues that are most stressed for a given task.

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