DEVELOPING AN EMPIRICAL SPATIAL SHOULDER MUSCLE ACTIVITY MAP

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INTRODUCTION

Although both empirical [1] and mathematical [2] approaches have been used to quantify shoulder muscle activity during task performance, these efforts have either focused on a few constrained tasks or lack extensive validation. Additional attempts to estimate shoulder exposures for work tasks have focused on identifying comfort levels [3] and strength requirements [4], and thus did not explore the physical consequences of performing work throughout a reach envelope. Unfortunately, these shortcomings compromise the practicality of their general adoption for ergonomic design applications, particularly for virtual environments.

The aim of this study was to establish a spatial (3-D positional) sensitivity of 14 shoulder muscles within a right-handed work envelope. The results will help develop a priori estimates of muscle forces and stresses, thus enabling proactive ergonomic designs to be evaluated for muscular loading. Additionally, the results provide extensive empirical evaluation data for existing mathematical shoulder muscle force prediction models.

METHODS

Fourteen university-aged males with no history of shoulder pain participated (age 22.0 ± 2.0 years). Bipolar surface electrodes were placed on 14 different sites on the right upper extremity (anterior, middle and posterior deltoid, biceps, triceps, infraspinatus, supraspinatus, pectoralis major sternal and clavicular insertions, latissimus dorsi, serratus anterior, and upper middle and lower trapezius). Muscle activity was recorded at 1500 Hz with a T2000 EMG system (Noraxon, Arizona, USA).

One hundred and forty 40N ramped directional seven second push tasks were performed (70 up; 70 down) within a right-handed reach envelope at specific locations spaced 20 cm apart along three axis: x (frontal plane -40 to 60 cm); y (saggital plane -10 to 50 cm); and z (coronal plane -20 to 60 cm). The origin of these axes was located at the center of the trunk at umbilical level. A Motoman HP50N (West Carrollton, OH, US) positioned the handle. Hand force was recorded with an MSA-6 transducer (AMTI, Watertown, MA, USA), and force feedback was provided to participants via custom LabView software (National Instruments, Texas, USA).

Exertion-specific muscle activity data were linear enveloped using a 4 Hz cutoff and normalized to activity levels recorded during three maximal voluntary contractions (MVC) for each muscle. Three-second central windows for each push task were evaluated for each muscle during each trial.

Two directional (up, down) 3-way ANOVAs were used for data analysis using the x, y and z positions as factors. Further, multiple linear regression was used to create predictive equations for each muscle for upward exertions to determine normalized muscle activity values.

RESULTS AND DISCUSSION

In both force directions, muscle myoelectric activity varied with spatial location (x, y, z). Significant ($p<0.05$) differences existed for all muscles, though specific muscles had variable spatial sensitivity that corresponded to their primary function. Many of these relationships were nonlinear.

Table 1-Prediction equations and variance explanation of several shoulder muscles for upward exertions.

Muscle	r^2	Prediction Equation
Pec. Sternal	0.81	$= 8.29 - 0.028(x) - 0.0003(z)^2 + 0.0072(x-22.09)^2 + 0.0008[(x-22.09)(z-27.41)]$
Supraspinatus	0.74	$= 2.13 + 2.11(x) + 0.14(y) + 0.12 (z) + 0.022(x-22.09)^2 + 0.0031(y-20.84)^2 - 0.002(z-37.41)^2 - 0.0012[(x-22.09)(z-27.41)] - 0.0013[(x - 22.09)(y-20.84)] - 0.00032(x-22.094)^3$
M. Deltoid	0.73	$= -5.55 + 0.16(x) + 0.21(y) + 0.16 (z) + 0.005(x-21.96)^2 + 0.0062(y-20.87)^2 + 0.0014(y-20.87)*(z-27.46)$
Lat. Dorsi	0.72	$= 6.78 + 0.023(x) + 0.034(y) + 0.019(z) + 0.001(x-22.09)^2 + 0.0017(y-20.84)^2 + 0.0011[(y-20.84)(z-27.41)]$
Upper Trap.	0.67	$= -1.022 + 0.083(x) + 0.16(y) + 0.2(z) + 0.003(x-22.09)^2 + 0.0033(y-22.84)^2 - 0.0014[(x-22.09)(z-27.41)]$
Lower Trap.	0.65	$= 3.74 + 0.17(x) + 0.024(y) + 0.045(z) + 0.0024(x-22.09)^2 + 0.004(y-20.84)^2 - 0.0019(z-27.41)^2$
Serratus Ant.	0.64	$= -3.47 + 0.081(x) + 0.24(y) + 0.23(z) + 0.005(x-22.09)^2 + 0.004(y-20.84)_2 + 0.0023[(y-20.84)(z-27.41)]$

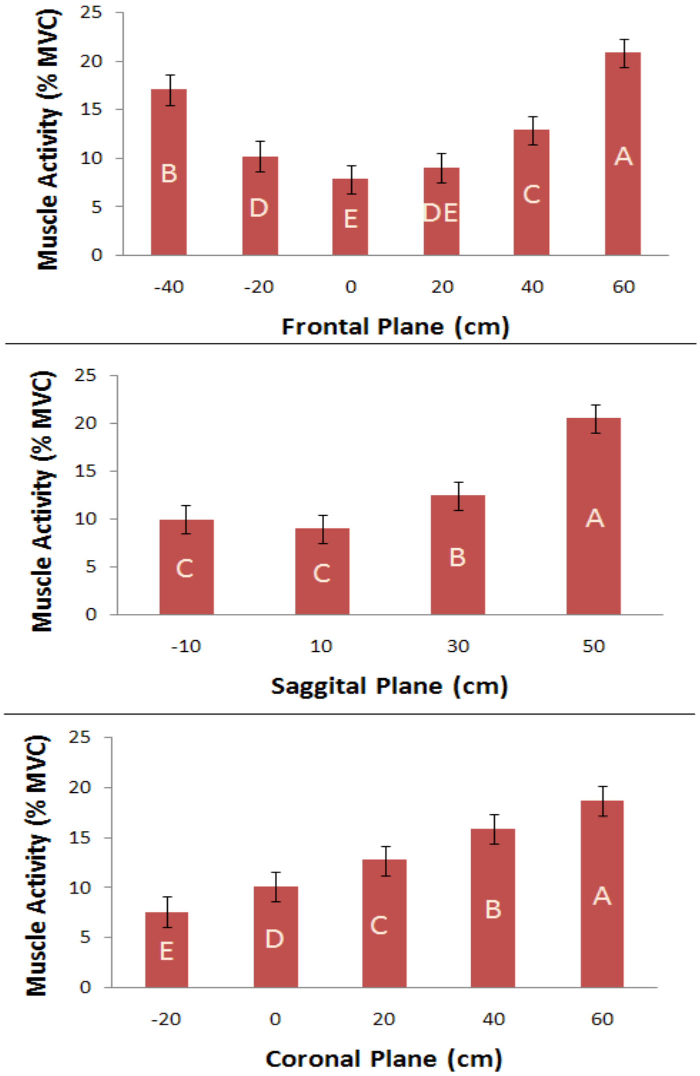

Figure 1 – Spatial variation effect on middle deltoid muscle activity for upward tasks. Different letters denote significantly different activity levels.

In general, muscle activation increased when exertions were performed further away from the system origin. In some cases values exceeded recommended limits for extended work [5]. Results reflecting these general findings are shown for a representative muscle, the middle deltoid (Figure 1).

Multiple linear regression produced spatially-based prediction equations for normalized muscle activity for each muscle (examples in Table 1). The variance explanation achieved by these equations exceeded 0.6 for all but three of the muscles monitored (posterior deltoid, lower trapezius, and biceps). With these equations, predictions of muscle activity for any location in the reach envelope are possible (an upward 40N push middle deltoid example on a 60cm surface is shown in Figure 2.

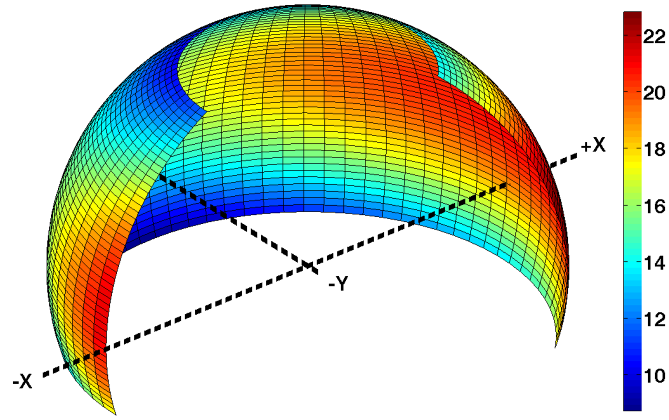

Figure 2 – Example of predicted muscle activity for middle deltoid on a 60 cm work surface Note the nonlinear shifts with spatial location of the exertion, which reflect the prediction equations generated.

CONCLUSIONS

Spatially dependent trends for all 14 muscles tested existed. They largely confirmed heuristic understanding of muscle function for specific exertion directions (i.e. arm elevators were more active as well as more accurately predicted during upward trials). In addition, we identified significant differences in activity level for each muscle between tested locations along each axis. More importantly, the results provide the research community with a previously unavailable, extensive dataset of shoulder muscle activity levels for multiple muscles throughout a large reach envelope.

The 3-D prediction equations created revealed interactions between axes and muscle activity for many shoulder muscles for upward exertions. This provides the foundational work for an advanced tool to evaluate the consequences on tissue-level loading of the spatial positioning of work demands. These initial equations will inform the expansion of predictive ability to include multiple hand force levels as well as additional exertion directions and evaluation of predictive model performance for interpolative and extrapolative situations.

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