Monitoring the Relationship between the Humerus and Clavicle Angles as Indicators for Neuromuscular Disorders

Anthony Gallagher and Yoky Matsuoka
The Robotics Institute
Carnegie Mellon University
Pittsburgh, PA 15213

ABSTRACT
To predict neuromuscular disorders, we are interested in monitoring upper limb movements continuously using wearable sensors. Shoulder muscle coordination is complex and for those with neuromuscular disorders, this coordination often fails. As monitoring the entire kinematics of the shoulder complex is nearly impossible to do continuously, we propose to simply track the humerus and clavicle angles using wearable and portable sensors as a way to continuously monitor and/or predict neuromuscular disorders. For healthy subjects, we found that the relationship between the elevation angles of the humerus and the clavicle are correlated with second order polynomials. Furthermore, this relationship is consistent for a given individual and is repeatable. Although the fits obtained differ slightly from subject to subject, the general shape of the fit is consistent across different individuals. Knowing the relationship between the elevation angles of the humerus and the clavicle for healthy shoulder movement, we will be able continuously to identify abnormal shoulder movements while patients participate in everyday activities.

INTRODUCTION
Abnormal movement jerkiness, velocity profile, tremor, and muscular coordination have all been reported to be observable symptoms of neurodegenerative disorders such as Parkinson's, Huntington's, or Multiple Sclerosis [1, 2]. These abnormal movements are also observed for patients recovering from strokes or spinal cord injuries. Although there are many ways to evaluate and monitor these neuromuscular disorders through tracking limb movements, we have chosen to do so by having patients use wearable and portable sensors to allow continuous observation.

As a first step toward this goal, we propose to track shoulder movement coordination. Shoulder movement is crucial for manipulation, and the complex muscles and joints of the shoulder must operate in harmony. Studies have shown that neuromuscular disorders can distort this relationship, reduce the range of motion of the joints, or change the average velocity of movements [3]. Tracking the entire shoulder complex, which is a combination of sternoclavicular, acromioclavicualar, scapulothoracic and glenohumeral joints having at least 14 degrees of freedom, is not realistic particularly if the movement needs to be measured continuously during normal activities. Attempting to simplify the representation of shoulder movements, Zatsiorsky [4] has shown that shoulder movement can be efficiently represented with 7 degrees of freedom, but that is still a large number of degrees of freedom to monitor. Our goal is to identify a distinctive and observable shoulder movement relationship that is consistent for healthy subjects but that fails for patients with neuromuscular disorders. To this end, we propose to isolate the observation to the elevations of the humerus and clavicle and understand the relationship between them in healthy subjects.

METHODS
Our wearable system consists of accelerometers that can track the movements as well as the orientation of the limbs. Figure 1 shows a

Figure 1. Our wearable and portable prototype system to track limb movements.

subject wearing our first prototype that uses a DC-coupled capacitive tri-axial accelerometer (Kistler, Inc. model 8392B10 K-Beam). It has a range of ±10g, weighs 42 grams and responds well to temperature variations. For our experiment in this paper, one accelerometer was placed immediately proximal to the elbow joint with Velcro. The gravitational vector is used to indicate the elevation of the humerus.

To validate the accuracy of our prototype and the shoulder model relations presented in this paper, an OptoTrak Motion Analysis System (Northern Digital, Inc.), which has a RMS positional accuracy of 0.1mm, was used. A total of three 6-Marker Probe markers were placed on the subject: One marker was placed on the forearm next to the accelerometer and the other on the clavicle. The frame of reference marker was placed at the top of the sternum.

We recorded shoulder movements from six subjects with no known neuromuscular disorders. With the accelerometer and the markers attached to their right arms, we asked subjects to lift their right arms five times at three different values of humerus abduction angles: 0° (straight out in front), 45°, and 90° (straight out to the side). To track the markers, we used the rotation matrix for each marker returned by the OptoTrak. A rotation matrix, R, is a 3×3 matrix that makes up a frame in terms of another frame such that:

$$\begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} = R \cdot \begin{bmatrix} x_r \\ y_r \\ z_r \end{bmatrix} \qquad (1)$$

where x_m, y_m, and z_m are the coordinates in the marker frame and x_r, y_r, and z_r are of the reference frame.

In our experiment, the y-axes of our marker's frames pointed perpendicular to the floor at zero elevation. Using the rotational matrix, we obtained the elevation of the humerus by simply tracking the orientation of these y-axes for the forearm marker. We projected these y vectors onto the Y-Z plane of the frame of reference by setting the x component of the vectors to zero. Our desired elevation angle is given by finding the angle this vector makes with the y-axes of the frame of reference. The elevation angles for both humerus and clavicle are determined by the formula $\theta = \text{atan2}(r_{22}, r_{23})$.

RESULTS

Analyzing the elevation angles obtained from the sensors, we found that there is a repeatable and consistent relationship between the elevation angles of the humerus and the clavicle. We calculated a quadratic fit for the data of each subject at each humeral abduction angle, and the typical fit is shown in Figure 2. For this typical subject, the fitted function for the abduction angle of 90° was:

$$\theta_c = 0.00261\theta_h^2 + 0.0425\theta_h - 23.9 \qquad (2)$$

where θ_c is the clavicle angle and θ_h is the humerus angle. For all subjects, the best-fitted functions were second order polynomials as in Figure 2. Fitted curves for all subjects and the average fit for the abduction angle of 0° are plotted in Figure 3. While the fitted curves are different from subject to subject, all subjects are able to reproduce movements that fit their own curve. In addition, the shapes of the curve

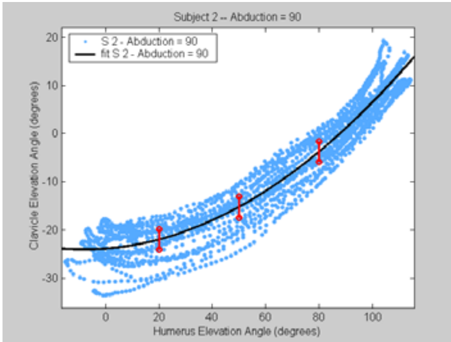

Figure 2. Humerus versus clavicle elevation angles for one subject. Dashed lines are actual movements and solid line is a fitted line with 1.802° std.

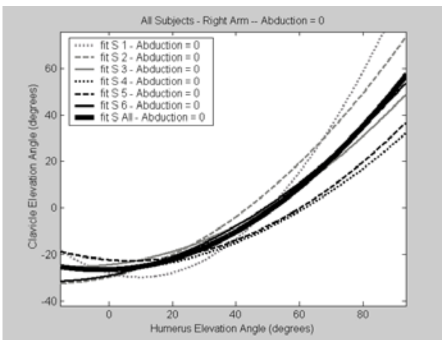

Figure 3. Fitted curves for all subjects and the average fit for the abduction angle of 0°. The thick line is the fitted curve for all subjects.

are similar enough among subjects to generalize to the average curves of $\theta_c = 0.0091\theta_h^2 + 0.0468\theta_h - 26.6002$ for the abduction angle of 0°, $\theta_c = 0.0054\theta_h^2 + 0.0905\theta_h - 26.0983$ for the abduction angle of 45°, and $\theta_c = 0.0040\theta_h^2 - 0.0447\theta_h - 19.5318$ for the abduction angle of 90°.

To verify that we can use the relationship established above with the accelerometer on the humerus alone, we acquired the humerus elevation angle from the accelerometer and then calculated the estimated clavicle angle. Note that the clavicle angle was not measured with the accelerometer for this experiment. The clavicle angle was calculated using the average curves. Figure 4 shows the calculated clavicle angle and the actual angle recorded by the Optotrak for an abduction angle of 90°. Even though we used the average curve of all the subjects as the base upon which to calculate the

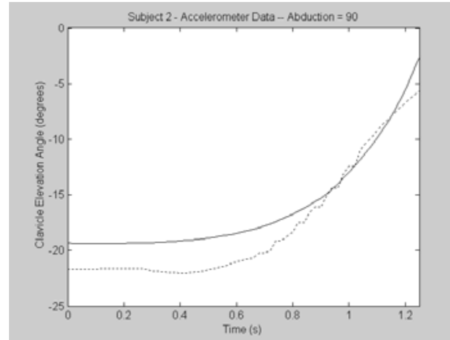

Figure 4. Calculated clavicle angle from the accelerometer on the humerus and actual angle recorded with OptoTrak over time ($R^2 = 0.8506$).

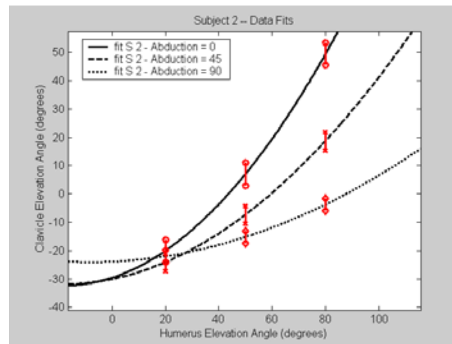

Figure 5. Fitted curves for humerus abduction angles 0, 45, and 90 degrees. The relationship between the humerus and clavicle angles can approximate the humerus abduction angle.

clavicle elevation angle, the root mean square is 0.8506 showing that this relationship can be reliably used to estimate the clavicle angle of healthy subjects, and therefore, there is no need to record it directly if we want to simply estimate the healthy clavicle movements.

While the accelerometer cannot measure the abduction angle of the shoulder (because it is parallel to the ground and its gravity vector does not change), the relationship between the humerus and the clavicle may be used as an indicator for the abduction angle. Figure 5 shows the three fitted curves for 0°, 45°, and 90° abduction angles for one subject. The standard deviation for each fit is small enough that we can reliably distinguish the abduction angle by simply observing the relationship between the humerus and clavicle angles. This relationship is true for each subject we tested.

DISCUSSIONS

We believe that our results will have a variety of applications other than those which we propose here. For example, Otani [5] proposed a model of the shoulder complex to create anatomically feasible animation figures. He also derived a relationship between the clavicle and humerus angles from a 2-parameter function of the elevation angle of the humerus and the abduction angle of the humerus. While this model succeeds in producing a reasonable approximation of animated human movements, there are items that could be included in his model. With his model, the relationship of the elevation angles is always linear for any given abduction angle. Furthermore, the model proposed starts with a clavicle elevation of 0° at a humerus elevation of 0°, which is not anatomically correct. From our observation, the clavicle elevation is negative when the humerus elevation is 0°. We believe that we can provide more realistic animated movement for a computer graphics human figure using our simple relationship between the humerus and clavicle angles.

Although the best fitting quadratics differed slightly from subject to subject, the average second order function we identified provides a way to approximate the relationship between humerus and clavicle elevations for a healthy subject while he/she makes simple movements. This relationship was shown to be consistently reproducible for each individual, creating a good baseline from which deviations and abnormal movements can be identified. We will further investigate the relationship between the humerus and clavicle angles during both task related movements and naturally executed movements as people make clavicle movements that are independent of the humerus.

In the near future, we plan to use our model for two different applications. First, we will use the relationship between the humerus and clavicle elevations for healthy subjects as a baseline to investigate the abnormal angle relationships in patients with neuromuscular disorders. We plan to use this as a diagnostic tool for those in a rehabilitation program and also as a way to predict the pathology of the disorder itself. Furthermore, we plan to identify abnormal relationships and use them as predictors for potential neurological or vascular problems.

The second application is to use this relationship to reduce the total number of sensors subjects must wear to monitor their movements. We are constructing a wearable accelerometer system with a minimum number of sensors as a way to monitor people's activities, analyze sports movements, and monitor and predict neurological disorders. Using the relationship we have established in this paper, we can eliminate a sensor on the clavicle and simply estimate the clavicle's movements from the humerus movements if we assume healthy movements. With this minimal sensor system, we plan to analyze other movement dynamics such as velocity and jerk of the entire limb.

REFERENCES

[1] Smith, M.A., Brandt, J., Shadmehr, R. "Motor disorder in Huntington's disease begins as a dysfunction in error feedback control" *Nature* 403 pp.544—549, 2000.

[2] Poizner, H; Fookson, OI; Berkinblit, MB; Hening, W; Feldman, G.; Adamovich, S. "Pointing to remembered targets in 3-D space in Parkinson's disease" *Motor Control* 2(3) pp.251—77, 1998.

[3] Y. Au, R. Kirsch. "EMG-Based Prediction of Shoulder and Elbow Kinematics in Able-Bodied and Spinal Cord Injured Individuals", *IEEE Transactions on Rehabilitation Engineering*, Vol. 8, No. 4, 2000.

[4] V. Zatsiorsky. *Kinematics of Human Motion*. Human Kinetics, IL 1998.

[5] E. Otani. *Software Tools for Dynamic and Kinematic Modeling of Human Motion.* Tech. Report MS-CIS-89-43, University of Pennsylvania, 1989.