Using Neural Network Models to Predict Shoulder Bone Response from Humerus Kinematics

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I. INTRODUCTION

By interpreting complicated datasets from different samples as a singular unit, Neural Networks (NNs) serve as powerful data fitting tools and establish relationships within complex, non-linear and noisy data. Recently, these methods have shown versatility in modeling human joint behaviour throughout various upper extremity [1], lower extremity [2] and gait [3] motions in human volunteers. This study aims to assess the viability of using these tools to predict the internal interactions within human joints under sub-injurious loading. As an example, NNs will be used to estimate the kinematic response of bones within the shoulder complex, as these interactions are understudied and underdeveloped in current human body models (HBM). These methods may prove useful as a means of developing cross-subject corridors for future HBM development and validation.

II. METHODS

Experimental Testing

Twelve shoulders from six Post-Mortem Human Subjects (PMHS) (three 50th percentile male and three 5th percentile female) were tested throughout a variety of sub-injurious loading cases [4]. A Vicon MX^{TM} 3D motion tracking system was used to measure the displacement and rotation of the bones (humerus, scapula, clavicle and sternum) throughout each motion trial. This testing was primarily conducted via manual manipulation of the PMHS's humerus under similar but varied loading duration and magnitude, making direct comparisons between individual trials difficult (Fig. 1). To account for this non-standardized dataset, NN models were developed for each subject to predict bone response from humerus kinematics.

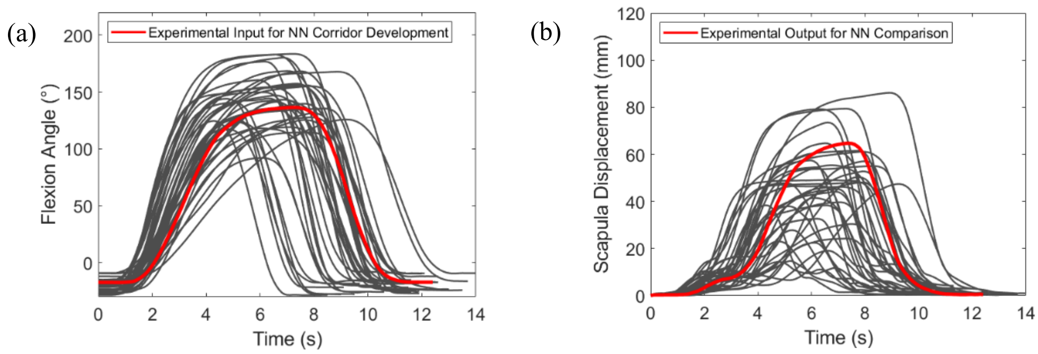

Fig. 1. Experimental (a) flexion angle (input) and (b) resultant scapular displacement (output) for all experimental flexion trials across the six PMHS. Each curve represents a full load-unload (flexion-extension) cycle. The red curve highlights an experimental test case that will be used for NN-based corridor development.

Subject-Specific Neural Network Development

Kinematic data from the experiment were divided into training and testing datasets. The testing set incorporated an additional manual rotation case, in which the humerus was moved randomly throughout the joint range-of-motion. All other data were included in the training set. The NN models consisted of four layers: the input layer, two hidden layers, and the output layer. The input layer contained the humeral displacement (x, y, z), rotation (yaw, pitch, roll), and their gradients (n=12). A tangent sigmoid transfer function was used between the input and the hidden layers [1]. The hidden layers were comprised of varying numbers of neurons, based on the performance of each model, and contained a positive linear transfer function between them. Finally, the NNs included a linear transfer function between the second hidden layer and output layer [1], which predicted either displacement (x, y, z) or rotation (yaw, pitch, roll) for an individual bone (scapula, clavicle, or sternum).

All NN models were trained within the MATLAB Neural Network Toolbox, with a maximum epoch of 500. On each iteration, a random 70% of the training data was used to train the model, while the remaining 30% was used for internal validation. Each NN was trained using different back-propagation algorithms, based on the

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performance of each model. These included: (1) conjugate gradient (CGB) with Powell-Beale restarts; (2) CGB with Fletcher-Reeves updates; (3) CGB with Polak-Ribiére updates; (4) scaled conjugate gradient; and (5) one-step secant back-propagation. After training, each NN was externally validated using the independent testing dataset. Intra-Class Correlation (ICC) and Root Mean Squared Error (RMSE) values were calculated for each model and averaged across the six subject-specific NNs for each output. In total, 108 NNs were trained and externally validated, each capable of predicting one output value for a single PMHS.

Corridor Development

Given the wide variance of experimental input conditions (Fig. 1(a)), it was not meaningful to develop biomechanical corridors for the output conditions measured in the six PMHS (Fig. 1(b)). Therefore, the subject-specific NNs were used to generate biomechanical responses within a common input condition. A single experimental humerus input dataset (red curve, Fig. 1(a)) was selected and fed through all six NN models to predict the bony kinematics of each subject, independently. The predicted response of each subject-specific model is presented as the grey curves in Fig. 2(a) and compared to the experimental output (red curves, Fig. 2(a) and (b)). With each model trained to estimate the associated PMHS' shoulder response, this process standardized the parameters of both the loading magnitude and duration, while unifying all six subjects into a single consistent dataset for corridor development. Corridors of mean (± 1 SD) bone kinematic response were then generated from the six independent, predicted models.

III. INITIAL FINDINGS

Development of subject-specific NN models is ongoing, but shows strong potential for use in biomechanics. Preliminary NN models of the 6-DOF response of the scapula and the rotational response of the clavicle correlate well with the validation cases (ICC = 0.81–0.96). The clavicle displacement and sternum NNs produced weak ICC scores (0.38–0.86) due to the marginal response of these bones relative to the humeral motion, as demonstrated by the low RMSE (0.374–1.198). Qualitative comparison using multibody reconstruction showed little meaningful difference between the kinematics measured experimentally with Vicon and NN-predicted kinematics with the same 6-DOF humerus motion as the input.

Using a common input condition with the subject-specific NN models enabled the development of a biomechanical corridor that essentially eliminated the variability introduced by the variance of the input conditions, and reflected only the biomechanical variability of the subjects. Along with the input conditions, these corridors can be used to validate the shoulder biomechanics of human body models.

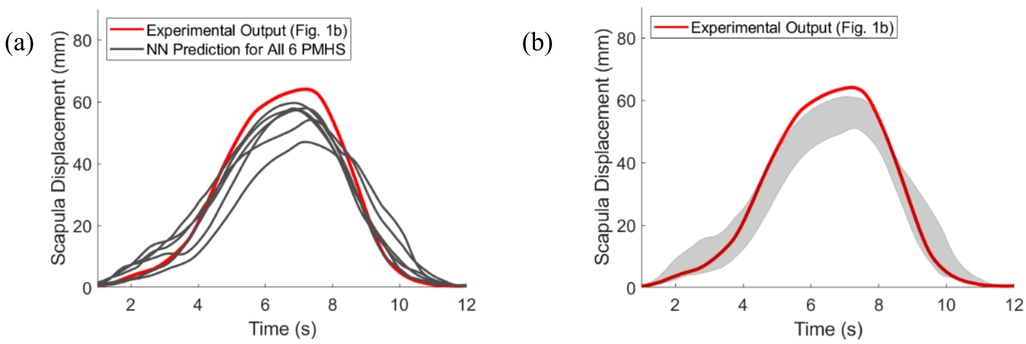

Fig. 2. (a) Six subject-specific NN models were developed to predict resultant scapular displacement from the selected experimental flexion input. The predicted results (grey curves) were compared to the experimental output (red curves in Figs 1(b) and 2(a) and (b). (b) A corridor of mean (± 1 SD) resultant scapular displacement was generated from the subject-specific NN models' predictions.

IV. DISCUSSION

This study applied NN techniques toward the prediction of shoulder bone interactions in response to sub-injurious loading. While many of the NN models still have room for improvement, their application in assessing multi-subject joint characterization showed great promise for both kinematic prediction and corridor generation. Further, these tools may have future applications in quantifying the biomechanics of other joint complexes.

V. REFERENCES

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