ISOMETRIC BENDING STRENGTH OF THE CERVICAL SPINE ESTIMATED FROM MOMENTS GENERATED BY OPTIMIZED ACTIVE MUSCLES IN FLEXION AND EXTENSION

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Introduction

- Isometric strength is a clinical tool for understanding the effects of neck pain (Ylinen et al. 1994, Chiu et al. 2002)

- The goal in understanding neck strength is to identify specific muscle involvement and recruitment during activity

- Little is known about muscle contribution to isometric bending strength, as EMG studies have only examined a few cervical muscles (Foust et al. 1973, Keshner et al. 1989, Kumar et al. 2001, Vasavada et al. 2002, Gabriel et al. 2004)

- Computational studies have been unable to predict volunteer cervical spinal strength for flexion and extension (Vasavada et al. 1998, Choi et al. 2000, Oi et al. 2004)

Objectives

- Predict cervical volunteer isometric bending strengths using a computational model

- Determine activation schemes for 23 cervical muscles in isometric bending

- Compare strength resulting from maximal muscle activations to that resulting from optimized muscle activations

Model Background

- A whole cervical spine ligamentous model with 23 pairs of geometrically and morphologically biofidelic cervical muscles, including 3 hyoids, was used

- Cervical muscle geometry and physiological cross-sectional area were derived from a cadaveric dissection and volunteer MRI study (Chancey et al. 2003)

- Flexion, extension, tension, compression, and shear properties are validated using experimental data (Camacho et al. 1997, Nightingale et al. 2007, Chancey et al. 2003, Van Ee et al. 2000)
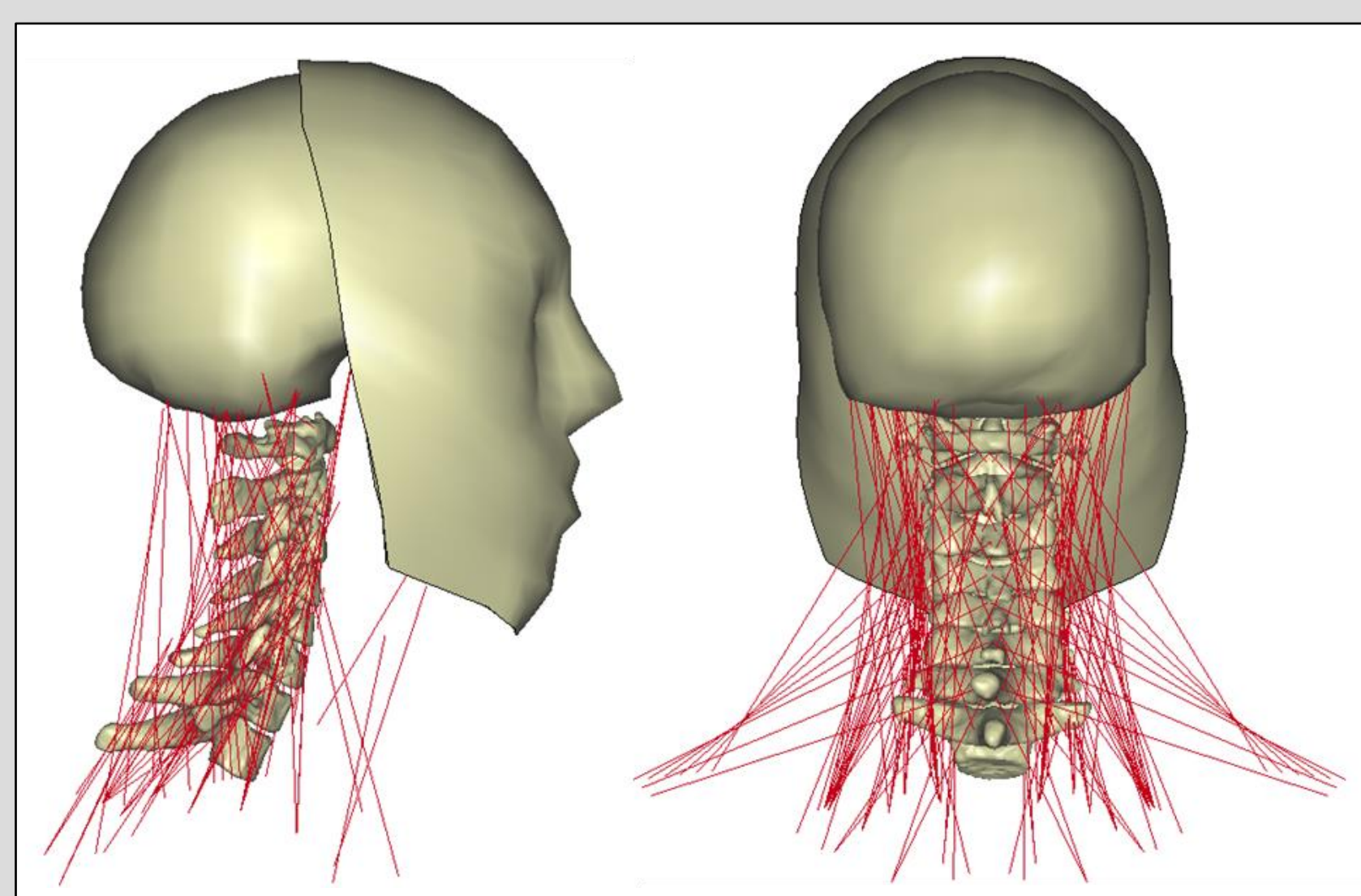
Validated FE cervical spine model showing included muscles.

Methods

- Model was optimized over 100 ms to simulate volunteer experiments of Vasavada et al. 2001. Horizontal force against a resistance pad was maximized and head motion from anatomically neutral position was minimized:

$$Maximize\ (\textstyle\sum_i F_i)$$

where: $F_i = \sum_{j=1}^{n} f_{i,j} \geq 0$ $\qquad f_{i,j} = PCSA_{i,j}\sigma_i$

$\sigma_i(\varepsilon) = \sigma_{i,passive}(\varepsilon) + \alpha_i \sigma_{i,active}(\varepsilon)$ (Myers et al. 1995)

- Optimization constraints were that the force in each muscle was nonzero ($F_i \geq 0, i = 1, \dots M$), and that the activation level (α) in each muscle was between 0 and 1 ($0 \leq \alpha \leq 1, i = 1, \dots M$), for all M muscles, which are each comprised of j strands

- Resulting muscle activation schemes were used to calculate isometric bending strengths along the cervical spine, which were compared with volunteer results (Vasavada et al. 2001) and with strengths derived from maximal ($\alpha = 1$) activation schemes
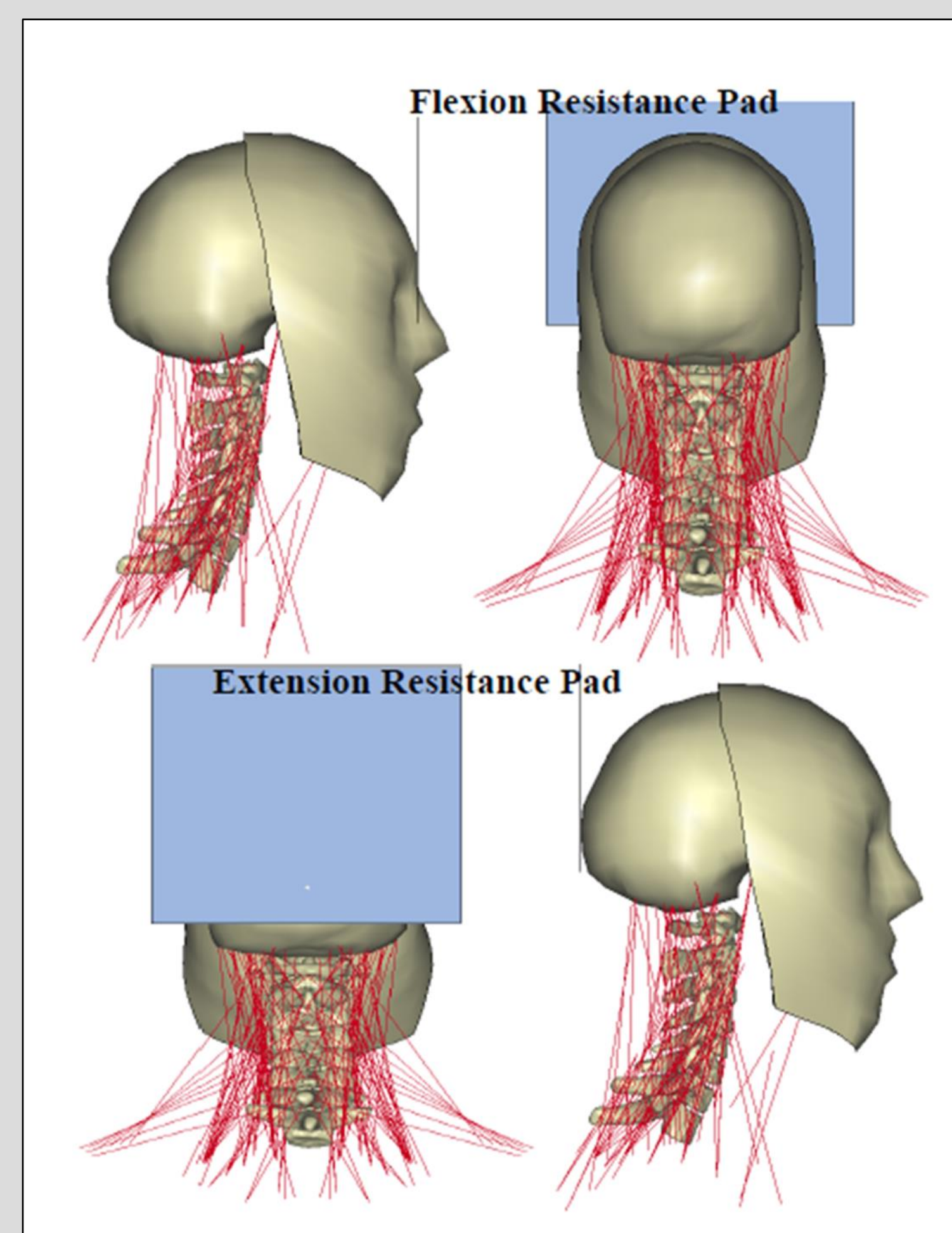

Results
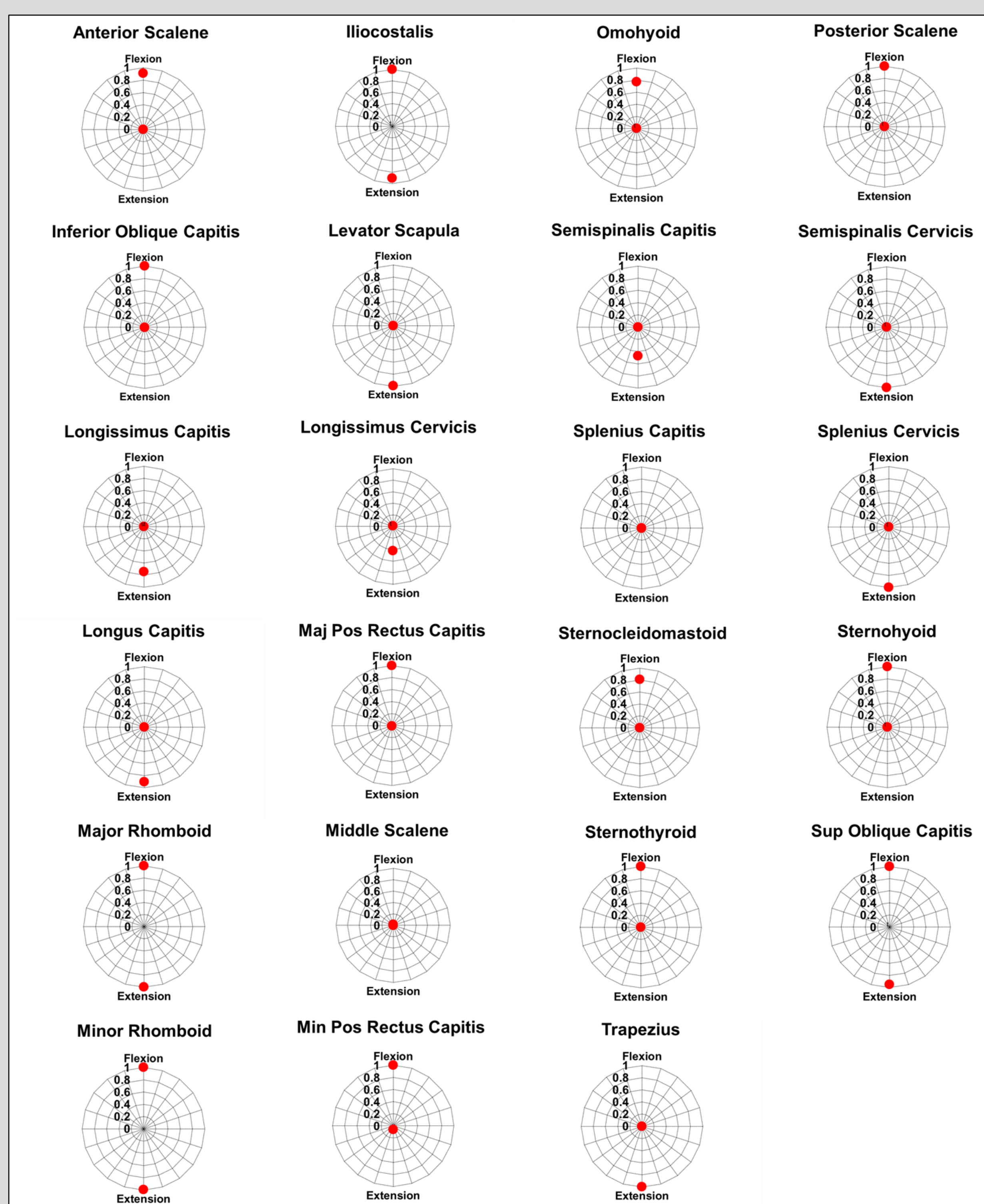
Polar plots of the optimized activation level (α) per muscle in response to applied loading. Applied loading scenarios were resistance to extension (flexion strength) and resistance to flexion (extension strength).

A range of muscle activity and contributions were found, with large multi-joint muscles being major contributors to extensor strength while the hyoids and sternocleidomastoid were major contributors to flexor strength.
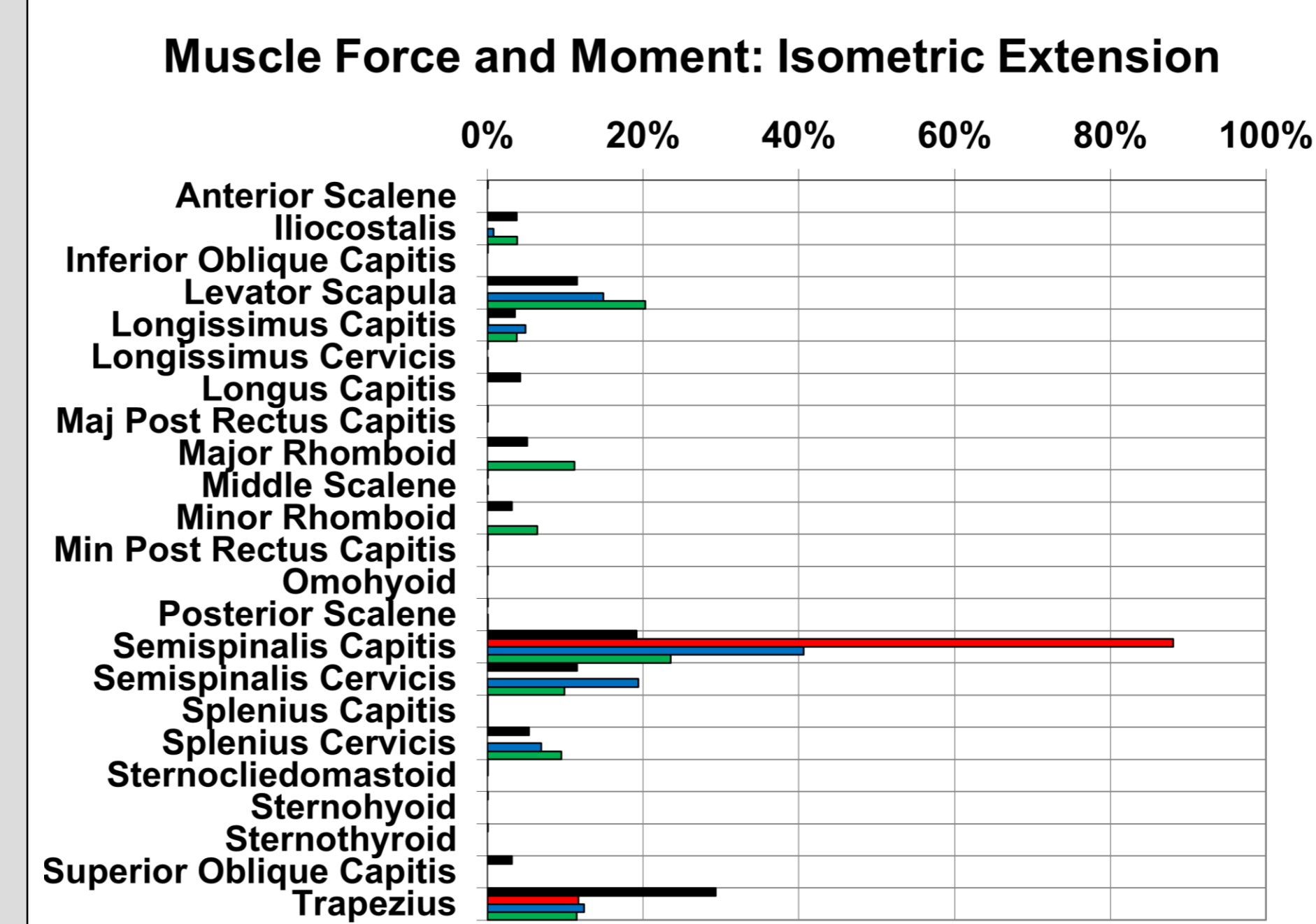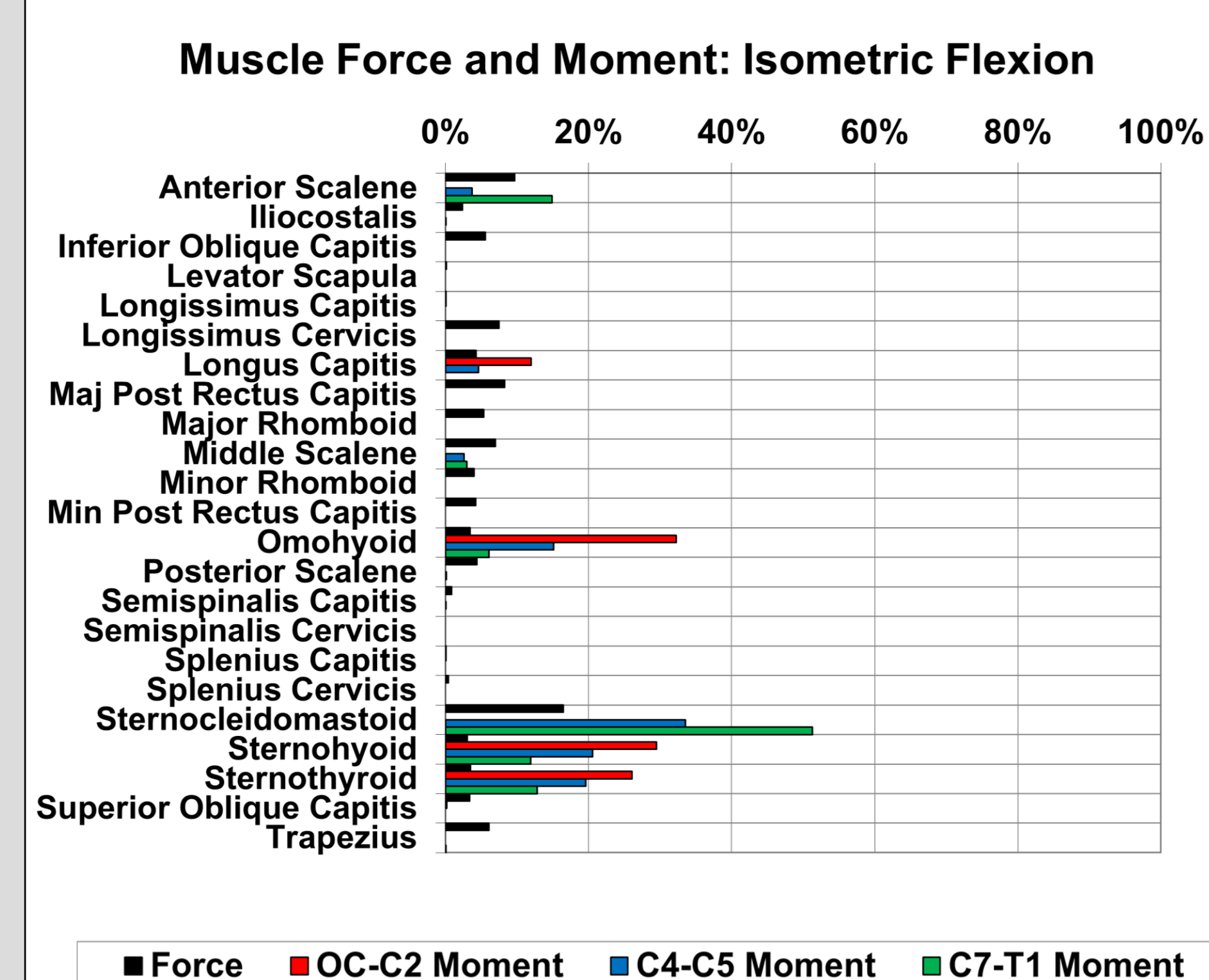
Percent of total force and moment generated by individual muscles under optimized activation schemes.

Conclusions

- Optimized muscle activations that resist loading while maintaining posture predicted volunteer isometric bending strength along the cervical spine

- Maximal activation (α = 1) of flexor and extensor muscles overestimated volunteer isometric bending strength in flexion and extension
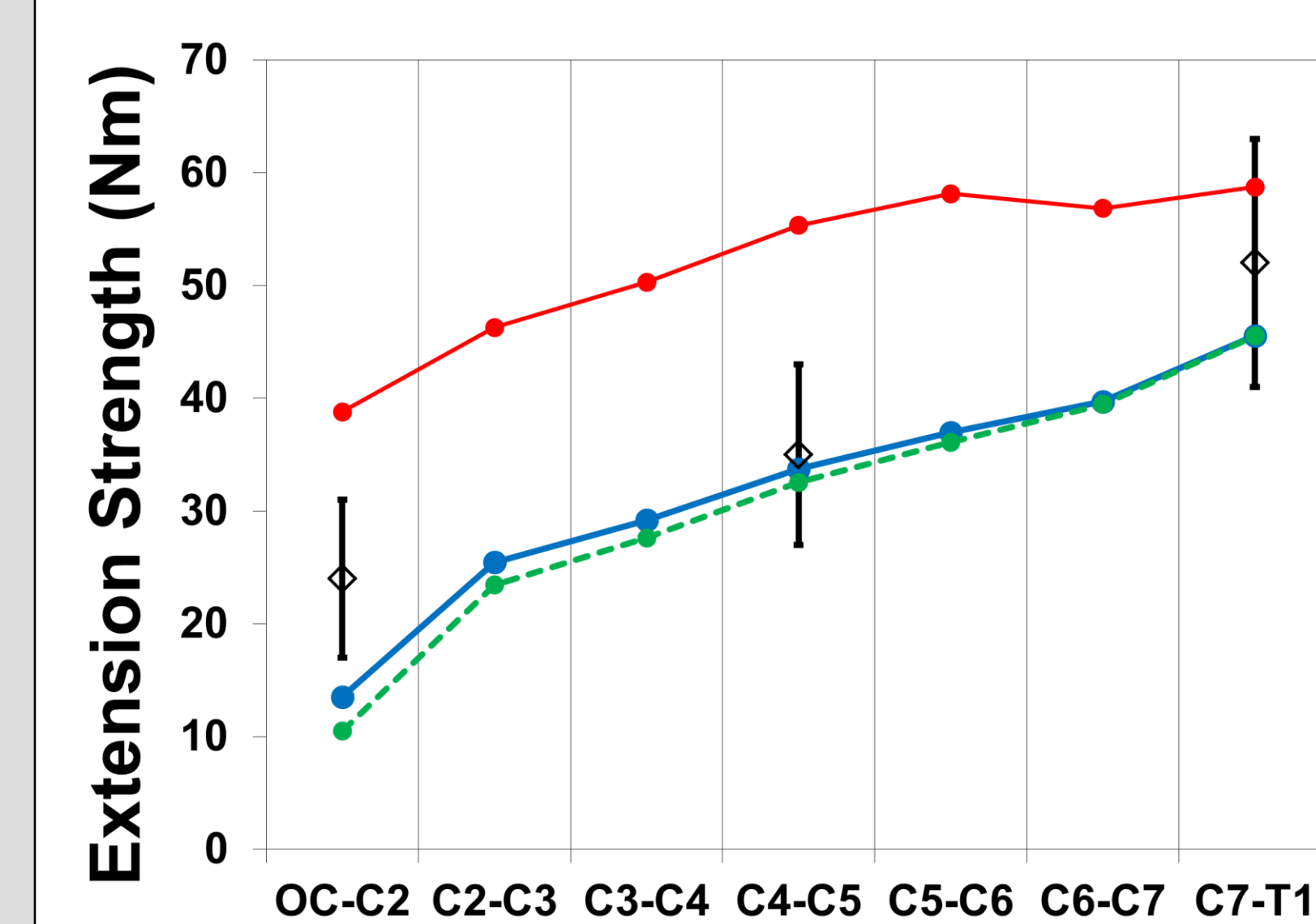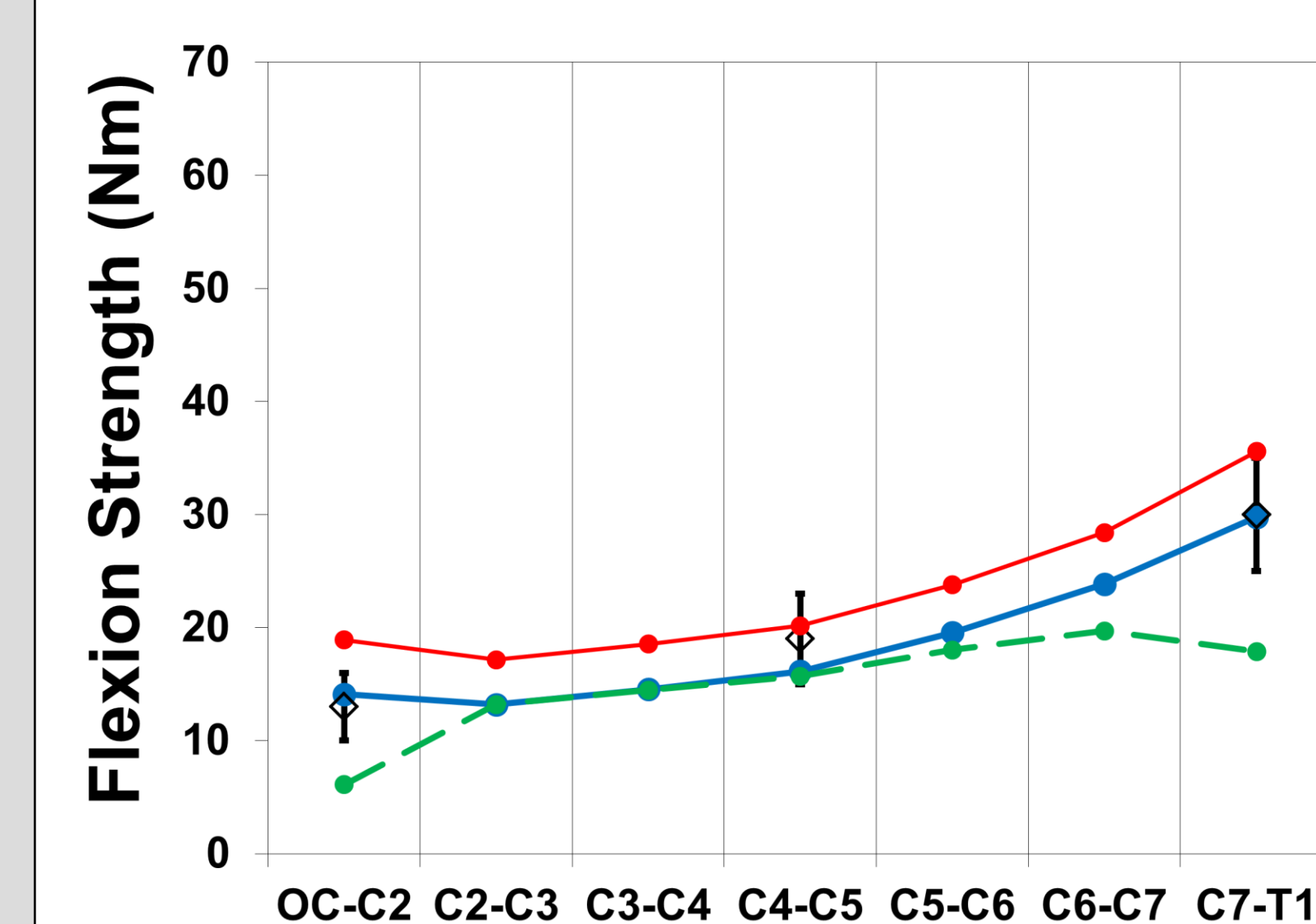
Moments produced by computational models compared to volunteer studies.

With maximal activation (α = 1), only the resulting flexor strength is near that predicted by Vasavada et al. 2001. With optimized activation, model predictions are within 2 Nm of reported volunteer strengths.

- Optimized muscle activation schemes for isometric bending (flexion and extension) included near maximal, sub-maximal, and co-activation of flexors and extensors

- Activation and recruitment of muscles were similar to those found in EMG studies (Keshner et al. 1989, Valkeinen et al. 2002, Vasavada et al. 2002)