Introduction

Musculoskeletal models of the hand have given us a deeper understanding of hand function, motor control, and joint loading.\(^1,2\) Pinch strength is an objective index of upper limb function and is used clinically as an indicator for treatment and rehabilitation.\(^3\) For a model to accurately represent the diversity of the population, parameters such as age, biological sex, anthropometric measurements, and neuromuscular disorders need to be incorporated.

Types of Musculoskeletal Models

- **Subject-Specific Models**,\(^4,5\)
  - Improved accuracy
  - Time and cost inefficient
- **Scaled generic models**
  - Represent average adult males
  - Low accuracy due to individual variation in musculoskeletal geometry and tissue
- **Generic Models**,\(^4,5\)
  - Scaled to represent the full range of heights (1\(^{st}\), 15\(^{th}\), 50\(^{th}\), 80\(^{th}\), and 97\(^{th}\) percentile) reported for four ages (7, 12, 16 and 30 years)\(^4\).

Types of Scaling

- **Linear Scaling**,\(^6,7\)
  - Anthropometric measurements:
    - Height, weight, BMI
  - Assumption: Force-size relationship is the same across individuals
- **Nonlinear Scaling**,\(^7,8\)
  - Digitization of medical images:
    - Computed tomography (CT)
    - Magnetic resonance imaging (MRI)
  - Bone geometries and muscle volume meshes from cadaveric specimens
  - Objective: Evaluate how well scaled, generic, hand models performing pinch simulations represent differences in age.

Methods

- **Musculoskeletal Models**:\(^9\)
  - 9 extrinsic and 5 intrinsic muscles of the wrist and thumb
  - 6 degrees of freedom (2 at wrist and 4 across thumb)
  - Initial thumb position: 15° CMC extension, 20° CMC abduction, 20° MCP flexion, and 40° IP flexion
- **Scaling of Models**:\(^9\)
  - Scaled to represent the full range of heights (1\(^{st}\), 15\(^{th}\), 50\(^{th}\), 80\(^{th}\), and 97\(^{th}\) percentile) reported for four ages (7, 12, 16 and 30 years)\(^9\).
- **Simulations**:\(^9\)
  - Lateral pinch force was measured for five sets of lateral pinch simulations using OpenSim (v. 3.3)
  - One-way ANOVA and Bonferroni procedure were used to compare simulation means for each color group [see below]

Results

Anthropometric scaling captured age-dependent differences in pinch strength

- Simulations that maximally activated the FPL (Simulation 1) are not significantly different from the experimental data.

Muscle activation strategies required to complete a task may shift as we age

- 7\(^{th}\) percentile model increased in pinch force from 50\(^{th}\) percentile male control strategy simulations (Simulation 2) to the age-matched control strategy simulations (Simulation 3).

Simulations can follow a similar muscle activation strategy as literature-based data

- The literature-based control strategy simulations (Simulation 4) were able to reach completion.

Simulations did not employ the optimal muscle fiber length to complete a pinch task

- Doubling the max. isometric force (Simulation 5) did not double the lateral pinch force

Discussion

Anthropometrically scaled generic hand models have the potential to elucidate changes in strength across the lifespan.

- Together, the simulations enhance our knowledge of when anthropometric scaling can accurately represent differences in age.
  - The majority of scaled models were able to replicate experimental data and ran to completion.
  - However, the smaller scaled models (<0.75, corresponding to below 132 cm height) implemented an unrealistic muscle control strategy to complete the task (see ECU activation in figure below) or failed to run to completion.

Differences between simulations and experimental data could be attributed to the fact that model scaling assumes a linear correlation between model parameters and anthropometric data.

Future research could explore how to incorporate age-related changes in muscle strength and/or activation patterns in order to model older adults.

Comparison Groups

- **Maximum Pinch Strength**
  - Simulation 1
  - Experimental Data
  - Simulation 2
  - Simulation 3
  - Simulation 4
  - Simulation 5

- **Muscle Control Strategy**
  - Articles that have measured muscle control strategy during lateral pinch task
  - Unique muscle control strategy for each model
  - Muscle activations controlled to match data collected through EMG
  - Muscle control strategy after doubling the max. iso. force

- **Linear Scaling**
  - 50\(^{th}\) percentile male control strategy & maximally activating the FPL
  - 50\(^{th}\) percentile male control strategy

Target Force

- Unconstrained
- 40 N

Descriptive Name

- FPL Exclusive
- Customary Control Strategy
- Double Isometric Force
- Intrinsic Thumb Muscles
- Extrinsic Thumb Muscles

Desired Output

- Max force
- N/A
- Effect of muscle control strategies on force achieved
- Relationship between scaling and force output

\*Simulation 3 was compared with the muscle control strategy and linearly scaled group


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