Evaluating Lateral Pinch Force Across the Lifespan through Scaled Musculoskeletal Models of the Hand

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INTRODUCTION

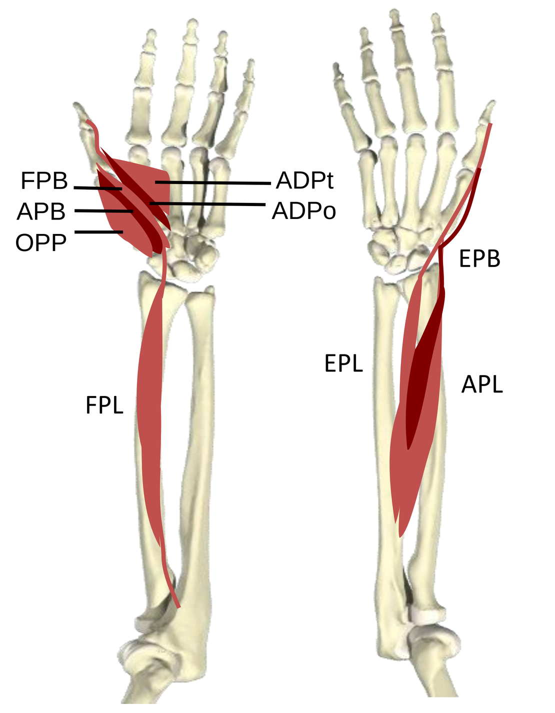
- Musculoskeletal models of the hand have given us a deeper understanding of hand function, motor control, and joint loading.[1,2]
- Pinch strength is an objective index of upper limb function and is used clinically as an indicator for treatment and rehabilitation.[3]
- For a model to accurately represent 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

Generic Models [4,5]
- Represent average adult males
- Low accuracy due to individual variation in musculoskeletal geometry and tissue

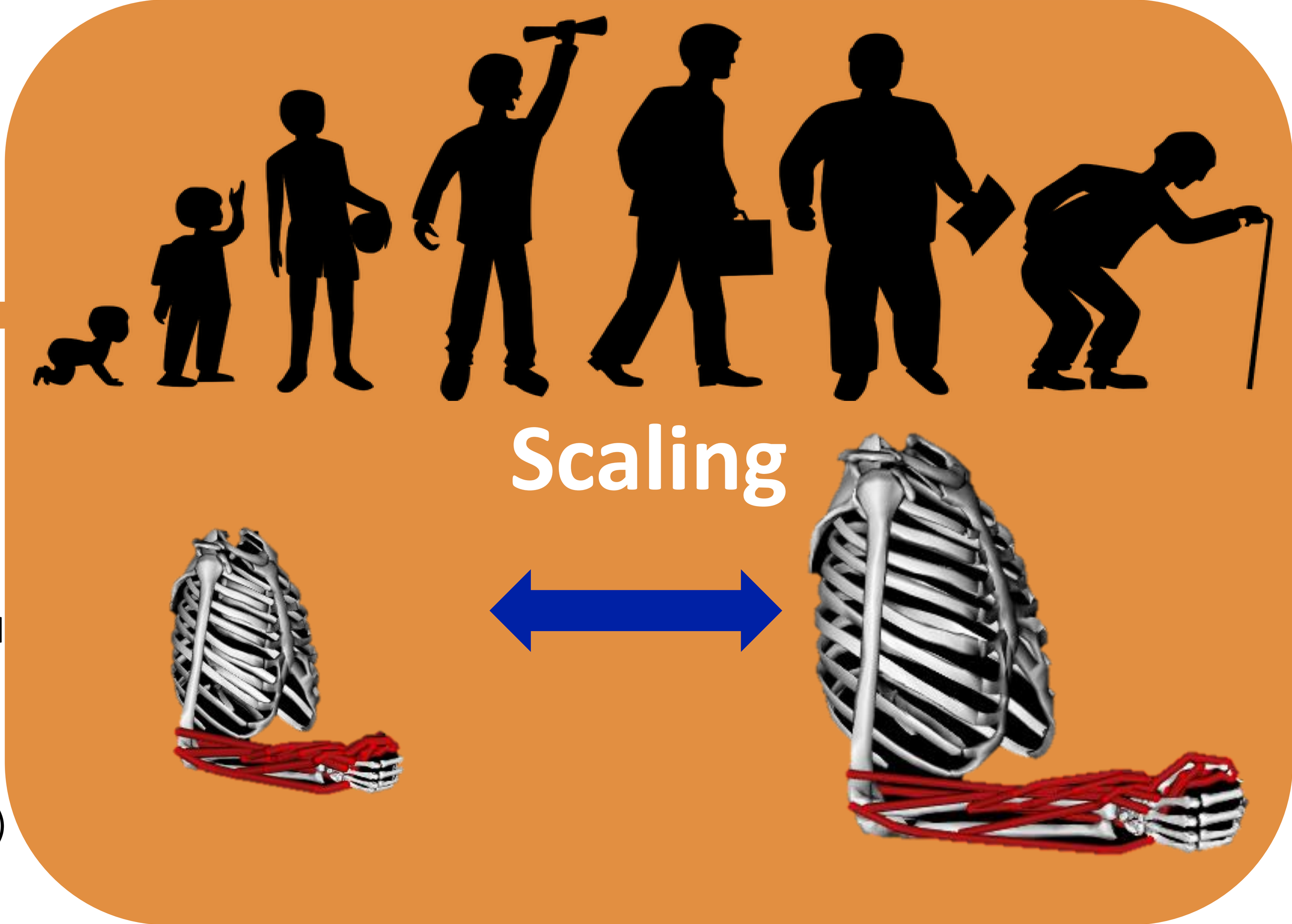


Types of Scaling

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

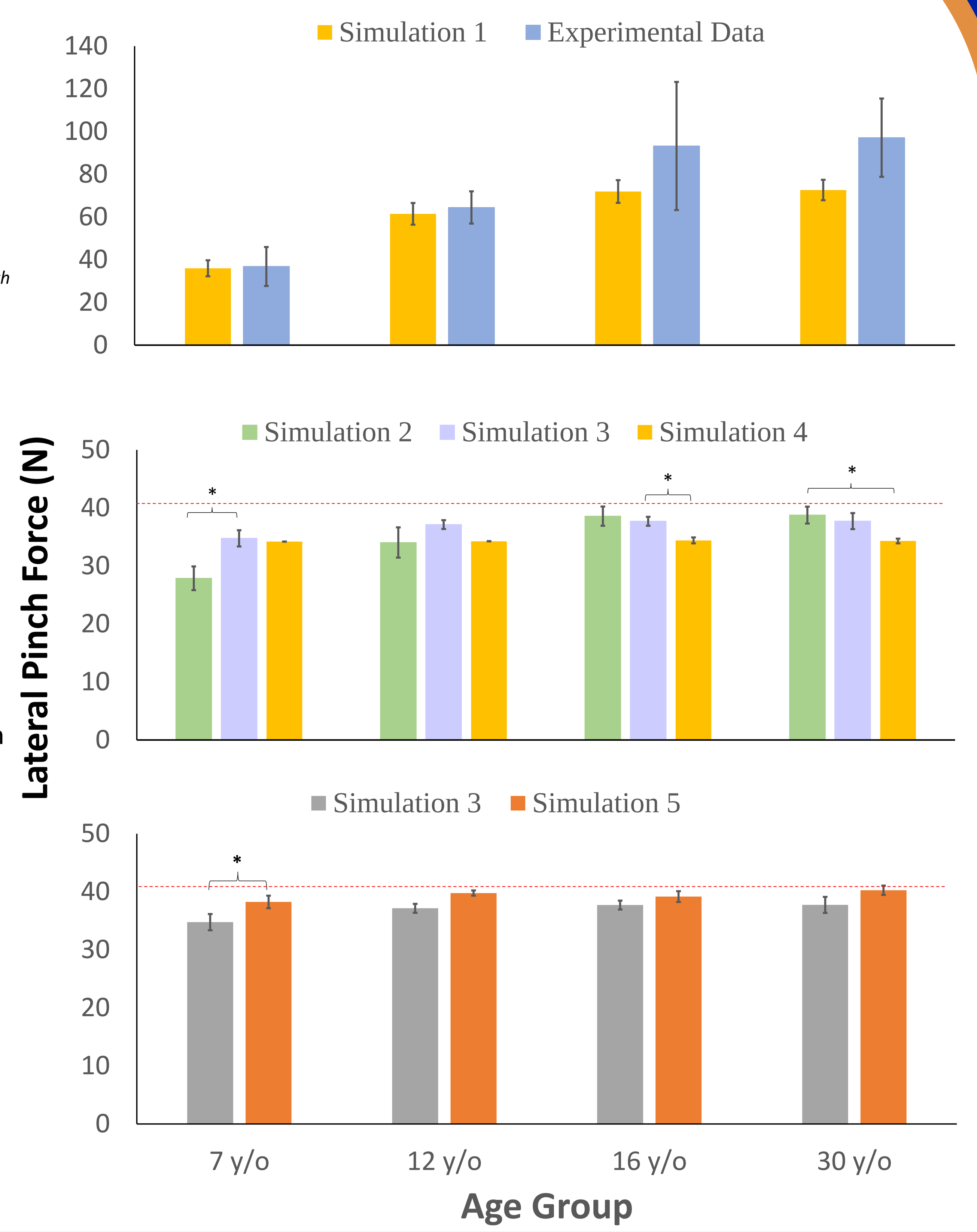
- *Musculoskeletal Models* [9]*:*
  - 9 extrinsic and 5 intrinsic muscles of the wrist and thumb
  - 6 degrees-of-freedom (2 at wrist and 4 across thumb)
  - Initial thumb position: 15° CMC extension, 20° CMC abduction, 20° MCP flexion, and 40° IP flexion
- *Scaling of Models:*
  - Scaled to represent the full range of heights (1st, 15th*, 50th, 80th, and 97th percentile) reported for four ages (7, 12, 16 and 30 years) [4].
- *Simulations:*
  - 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)

Comparison Groups	***Maximum Pinch Strength***		***Muscle Control Strategy***			***Linearly Scaling***
Group Name	**Simulation 1**	**Experimental Data**	**Simulation 2**	**Simulation 3[a]**	**Simulation 4**	**Simulation 5**
Input Config.	50th percentile male control strategy & maximally activating the FPL	Articles that have measured muscle control strategy during lateral pinch task	50th percentile male control strategy	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
Target Force	Unconstrained	Unconstrained	40 N			40 N
Descriptive Name	FPL Exclusive	Experimental Data	Customary Control Strategy	Age-matched Control Strategy	Literature-based Control Strategy	Double Isometric Force
Desired Output	Max force	N/A	Effect of muscle control strategies on force achieved			Relationship between scaling and force output

[a] Simulation 3 was compared with the muscle control strategy and linearly scaled group

RESULTS

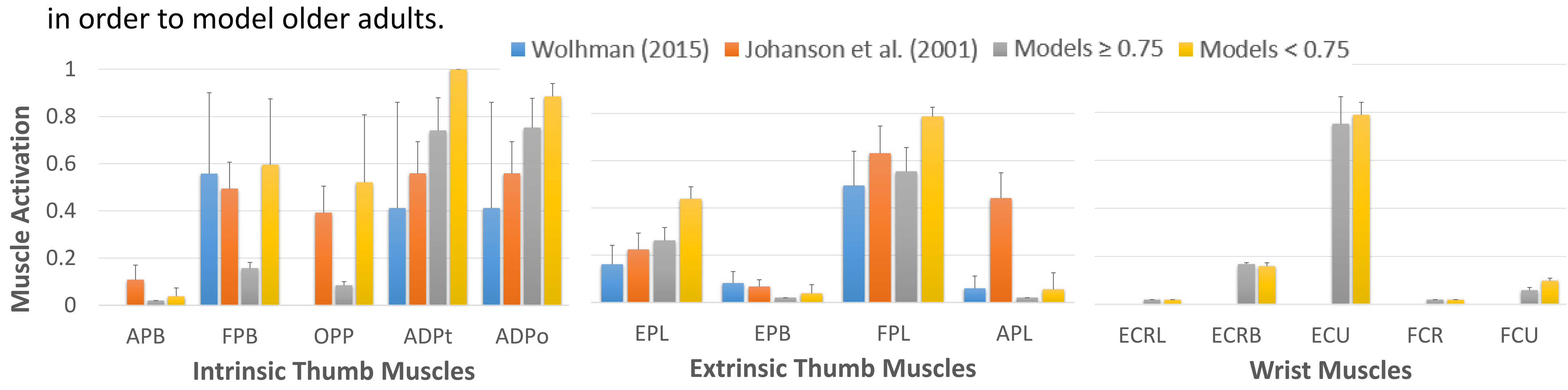
- Anthropometric scaling captured age-dependent differences in pinch strength
  - Simulations that *maximally activated the FPL* (Simulation 1) are not significantly different from the experimental data.
- Muscle activation strategies required to complete a task may shift as we age
  - 7 y/o model increased in pinch force from *50th 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 represents 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.



More information can be found at: Ordonez Diaz, T., et al. 2021. *J Biomech*, 123, 110498. doi:10.1016/j.jbiomech.2021.110498.

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