



# All muscles are redundant, but some are less redundant than others

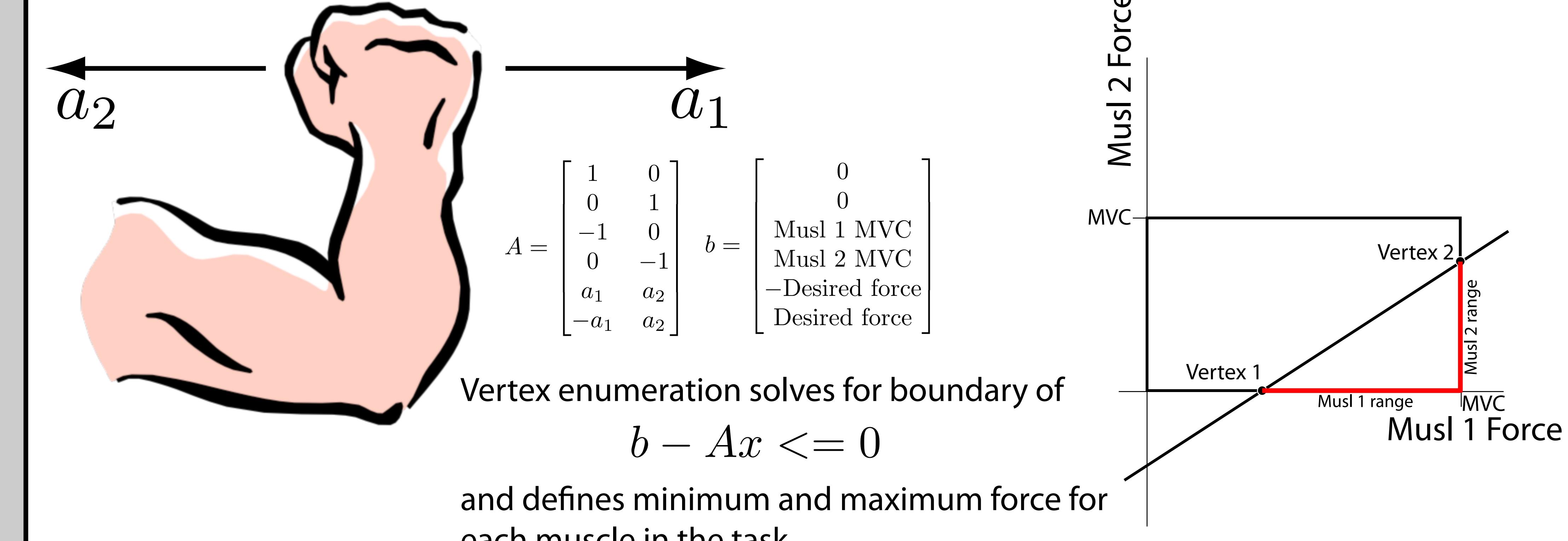
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## Introduction: The two distortions of muscle redundancy

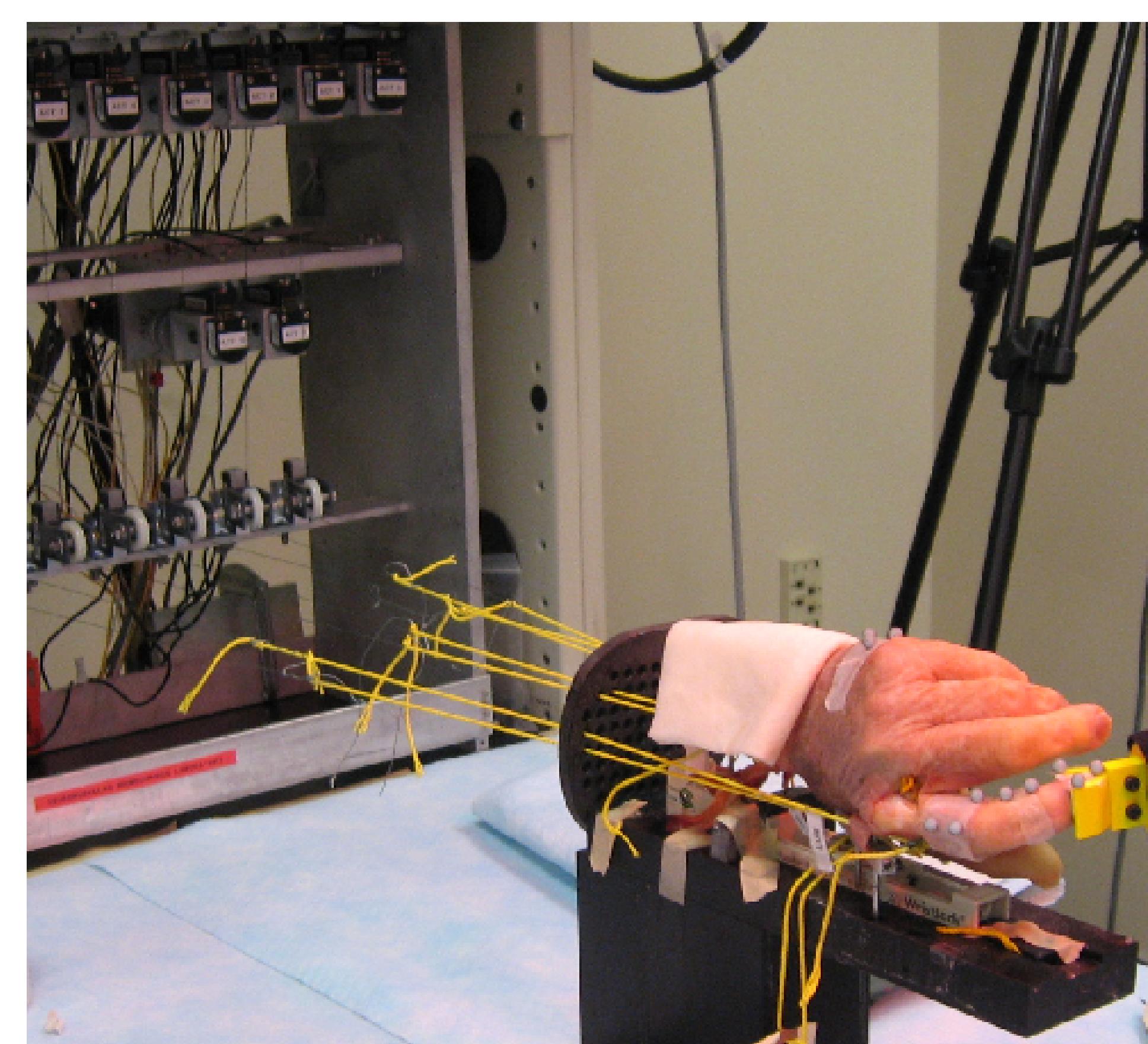
1. If you lose a muscle, the other muscles can compensate
2. There are an infinite number of different combinations of muscle forces that will produce the same joint torque.

## Analyzing redundancy: the vertex enumeration problem

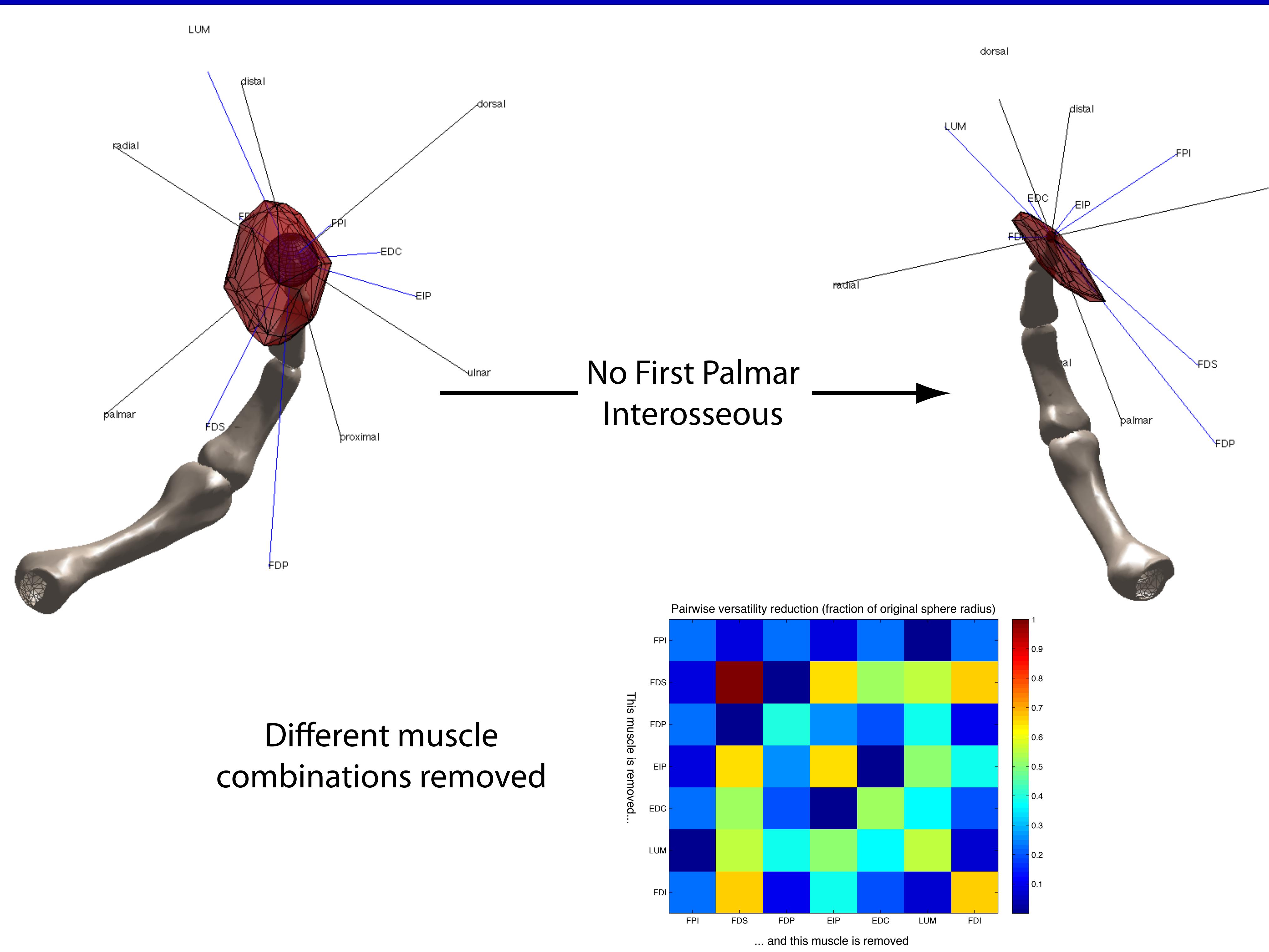


## Experimental preparation and approach

1. Fresh cadaver arm resected at mid-forearm, dissected to reveal tendons for index finger.
2. Tendon tensions computer controlled.
3. Index fingertip attached rigidly to 6 DOF load cell (JR3, Woodland, CA).
4. Feasible force set measured using all possible combinations of active and inactive muscles:  
Input 1: [1,0,0,0,0,0] : Record JR3 reading  
Input 2: [0,1,0,0,0,0] : Record JR3 reading  
...  
Input 7: [0,0,0,0,0,1] : Record JR3 reading  
Input 8: [1,1,0,0,0,0] : Record JR3 reading  
...  
Input 127: [1,1,1,1,1,1] : Record JR3 reading  
1 = maximum tendon tension



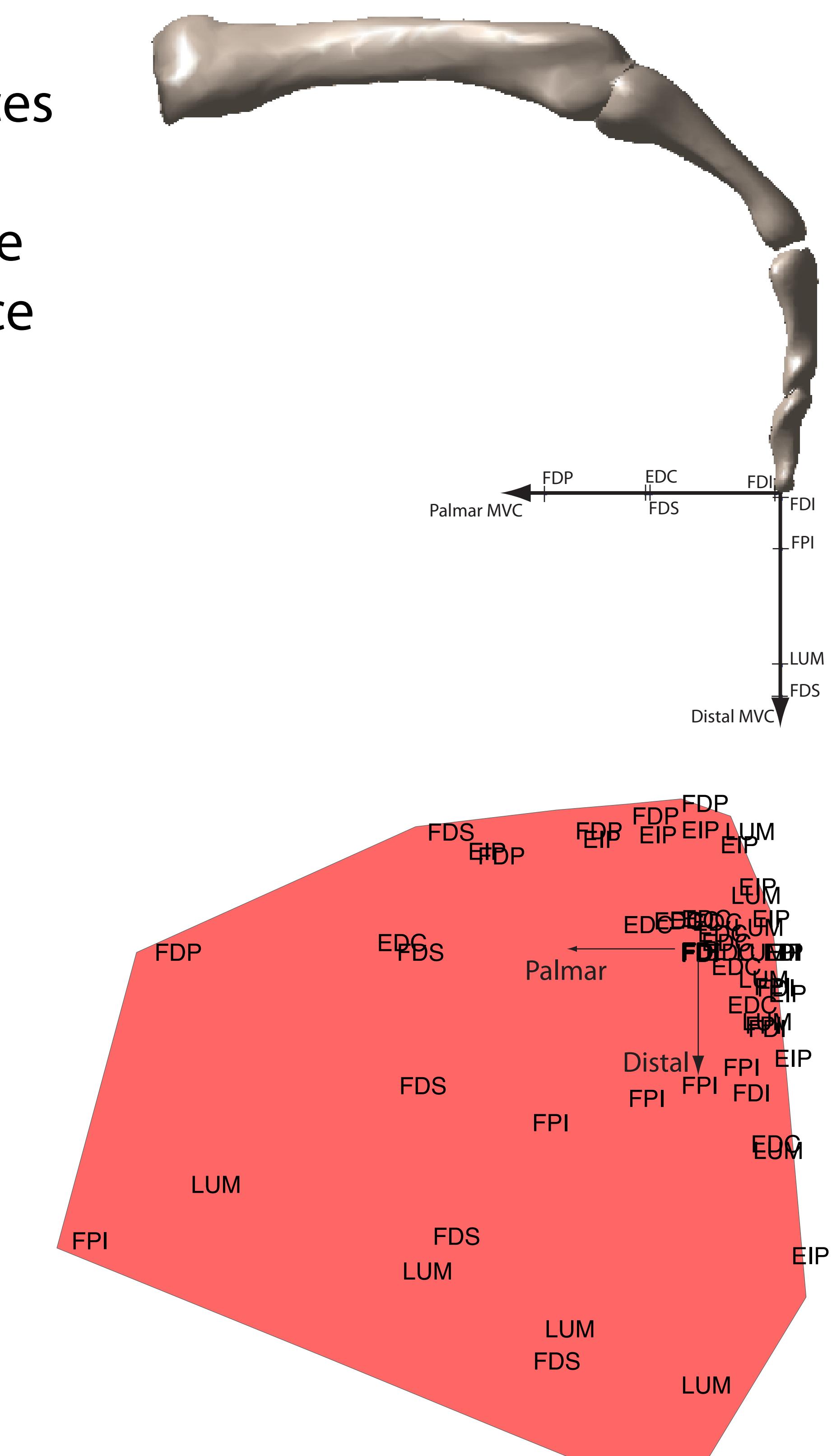
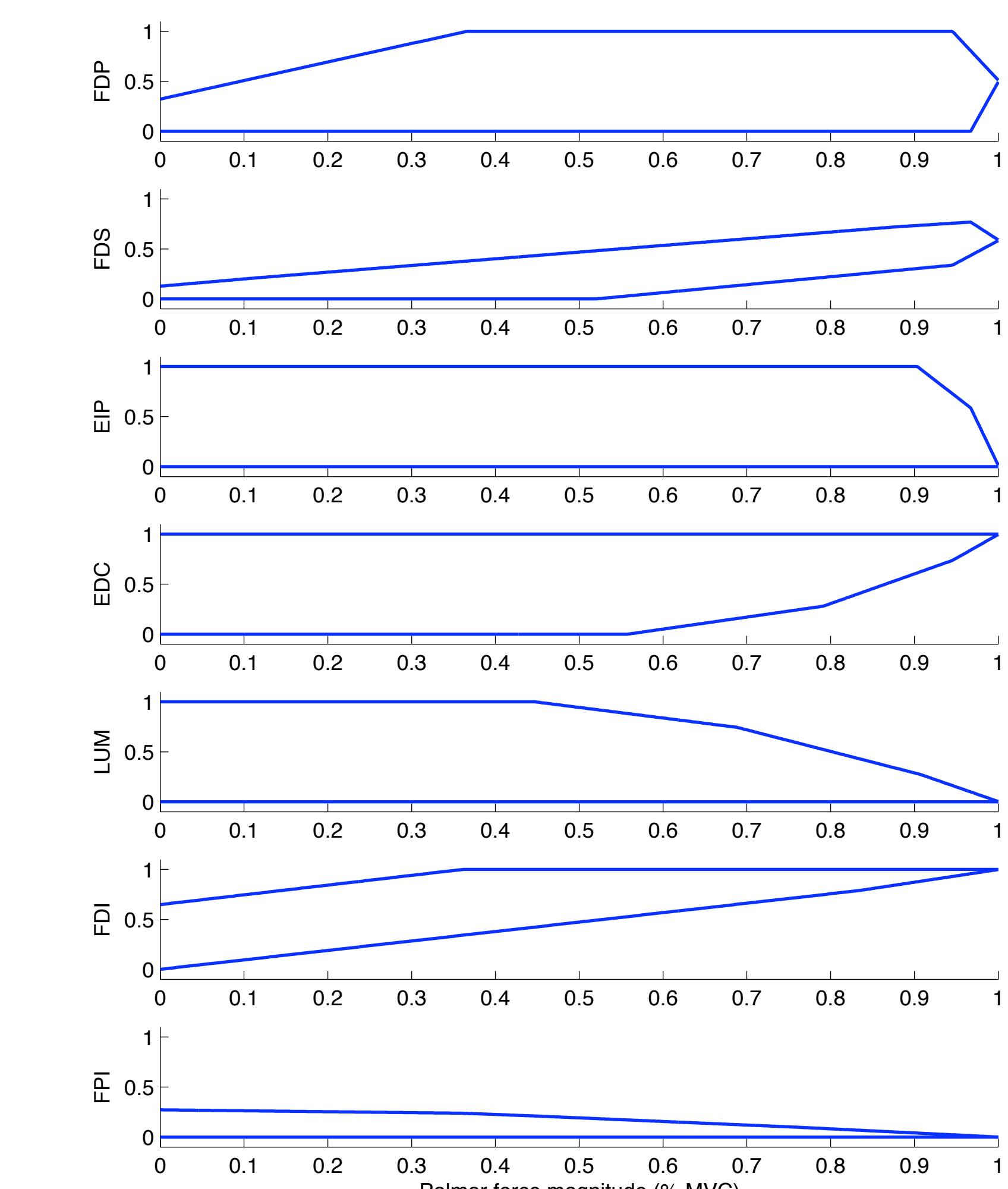
## Truth Number 1: The feasible force set collapses



## Truth Number 2: Strange muscles become necessary for submaximal force

Vertex enumeration reveals

1. FDI necessary for even the smallest forces
2. EDC/FDS required at 50% palmar force
3. FPI required at less than 30% distal force
4. Feasible activation ranges shrink as force magnitude increases.
5. Many muscles become necessary in different force directions.



## Conclusion: Don't assume muscles are redundant!

1. Just because the number of muscles exceeds the number of degrees of freedom doesn't mean that these muscles are redundant.
2. Redundancy depends on musculoskeletal geometry and needs to be quantified.
3. The CNS may not have as much latitude in choosing muscle activations as is usually assumed.
4. The muscular system is not robust to muscle weakness.

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### References

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