

Force variability as an indicator of neural control dimensionality

Jason J. Kutch, Ph.D.



in collaboration with

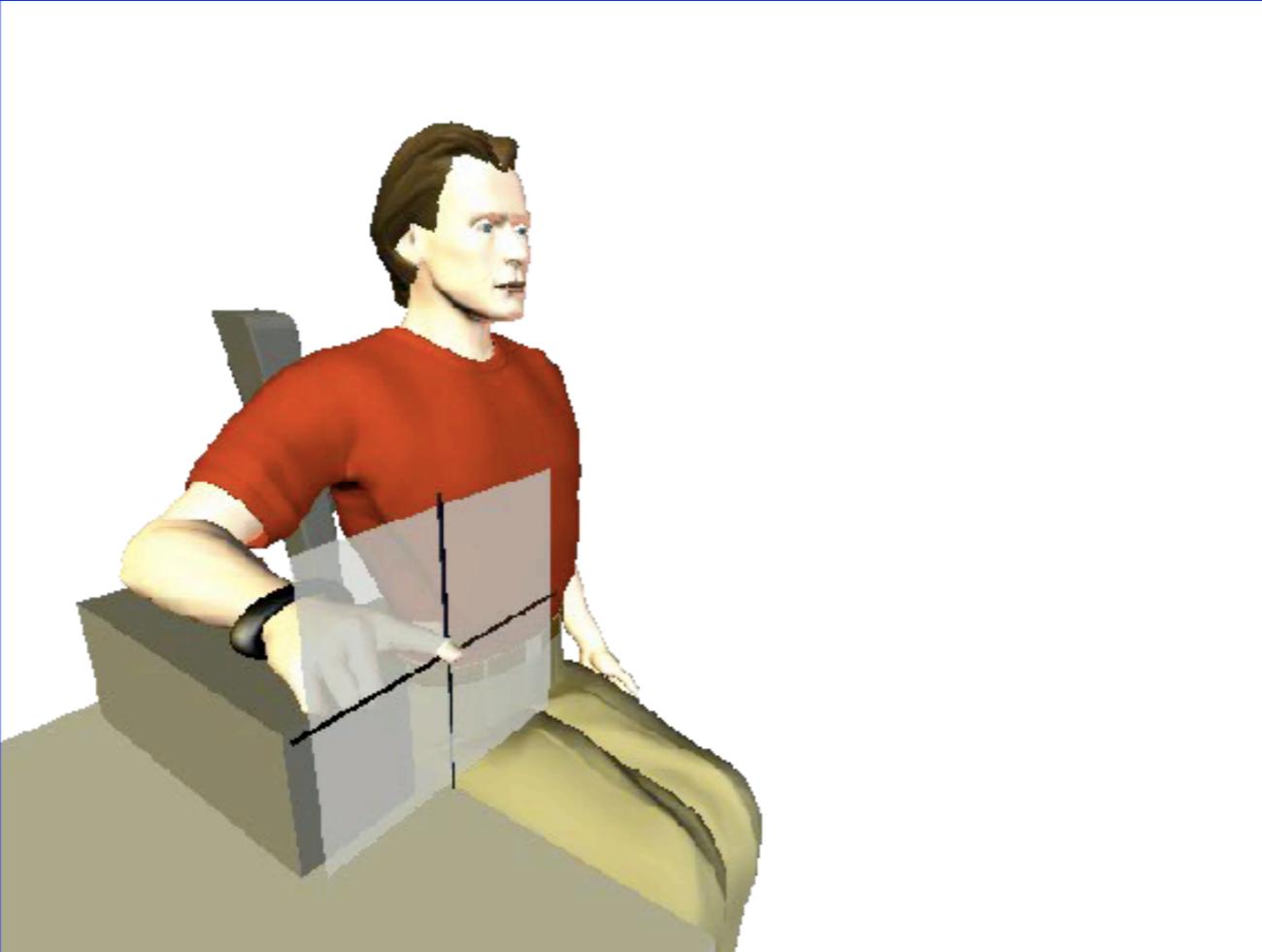


Applied and Interdisciplinary Mathematics
University of Michigan, Ann Arbor, MI

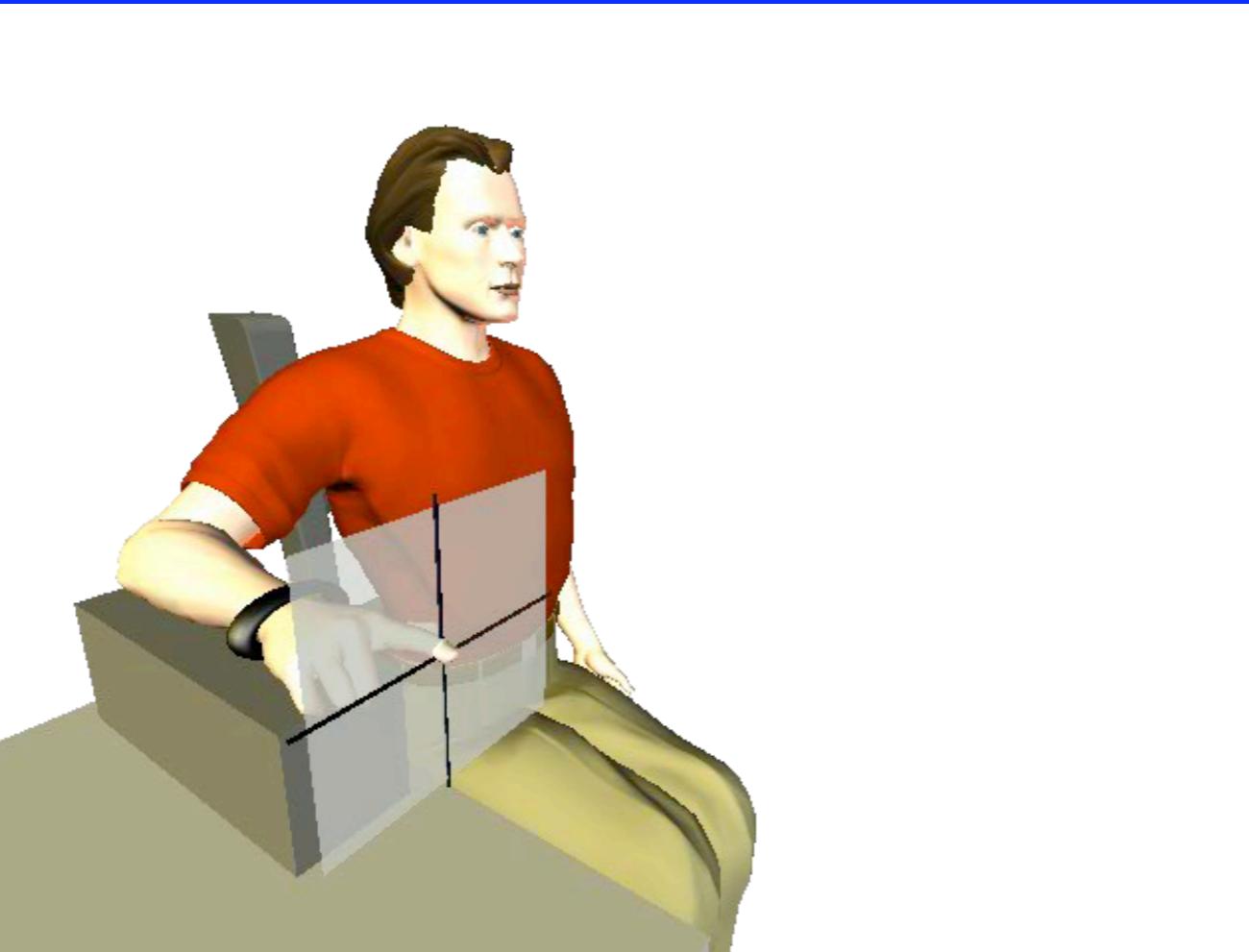
Sensory Motor Performance Program
Rehabilitation Institute of Chicago, Chicago, IL

Task dimension determines output dimension

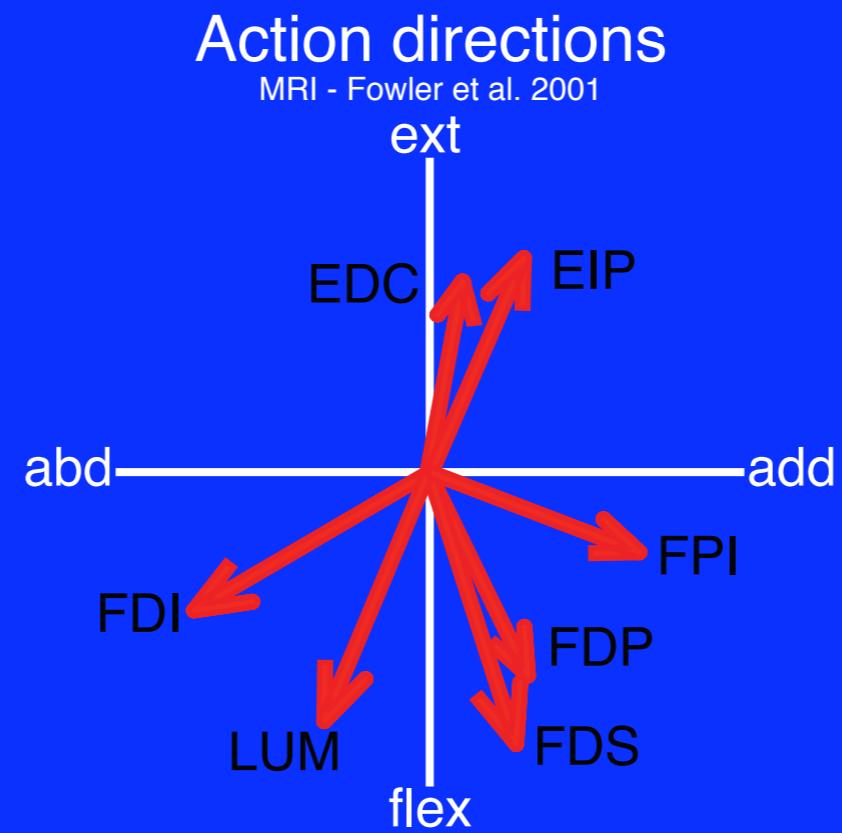
Task dimension determines output dimension



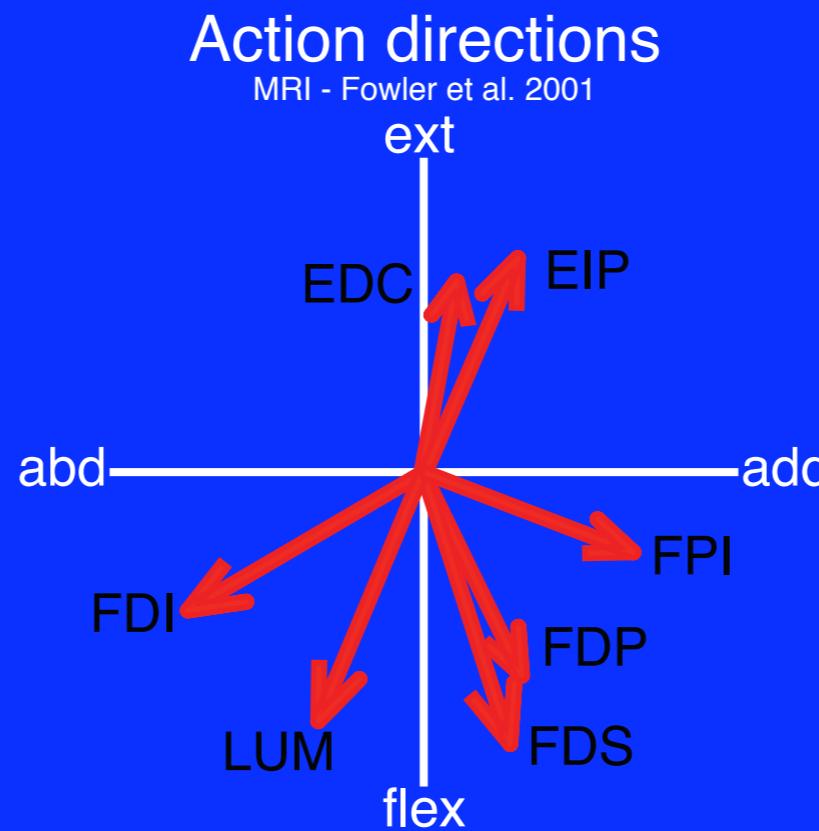
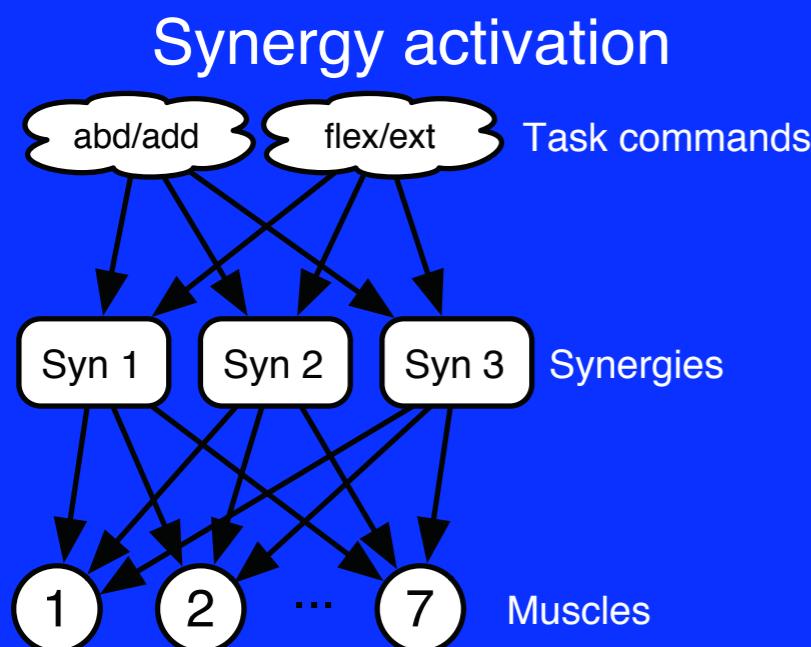
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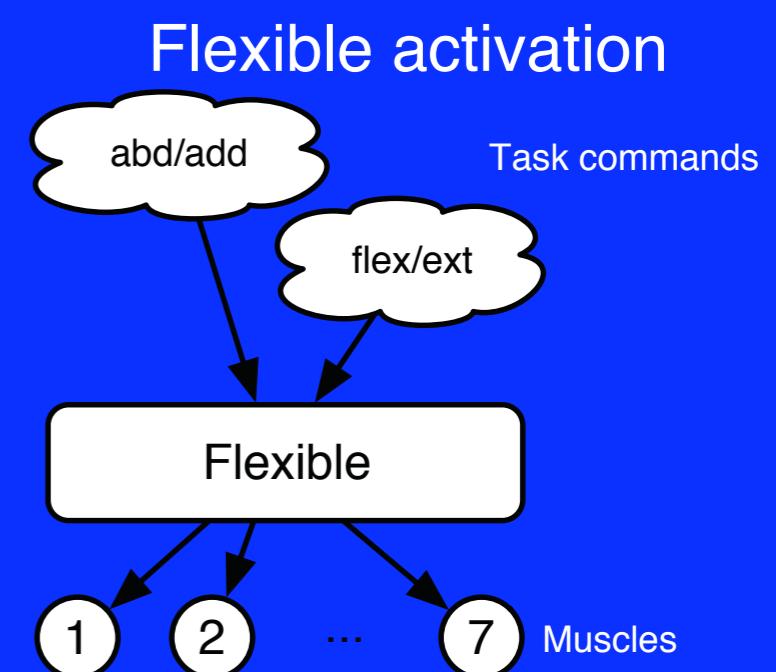
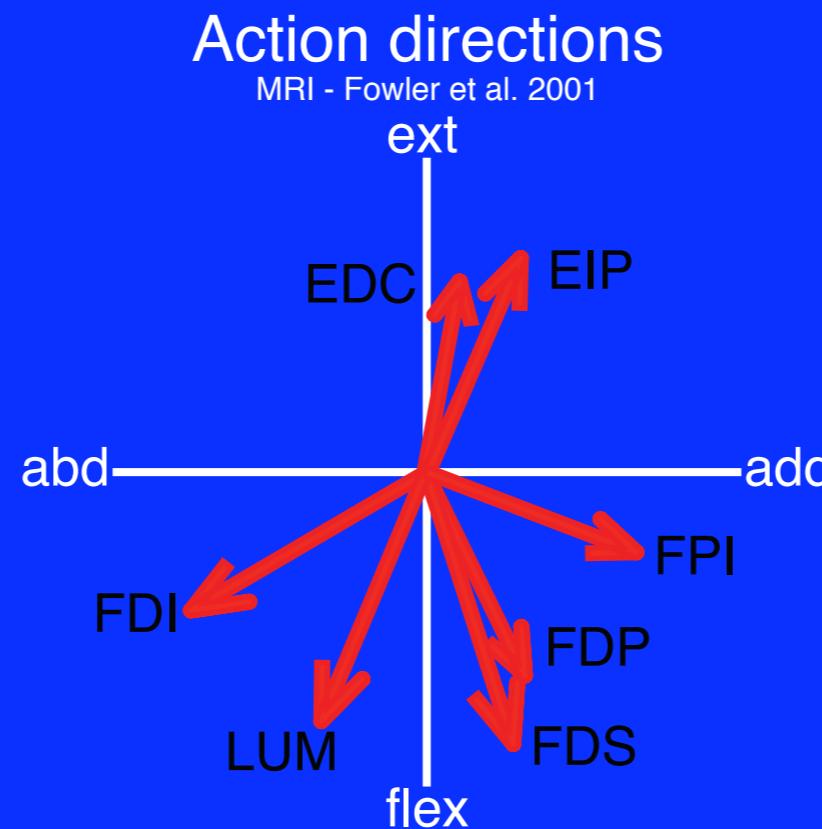
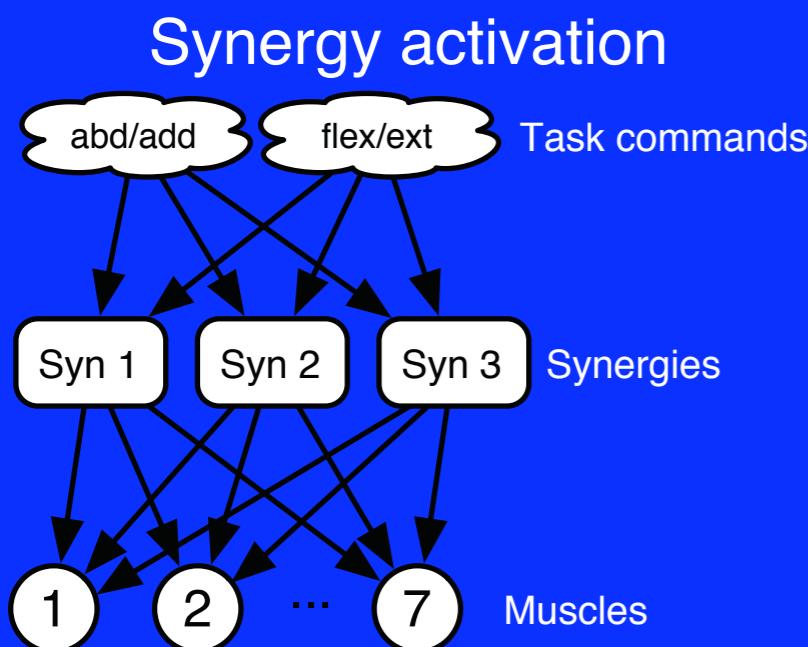
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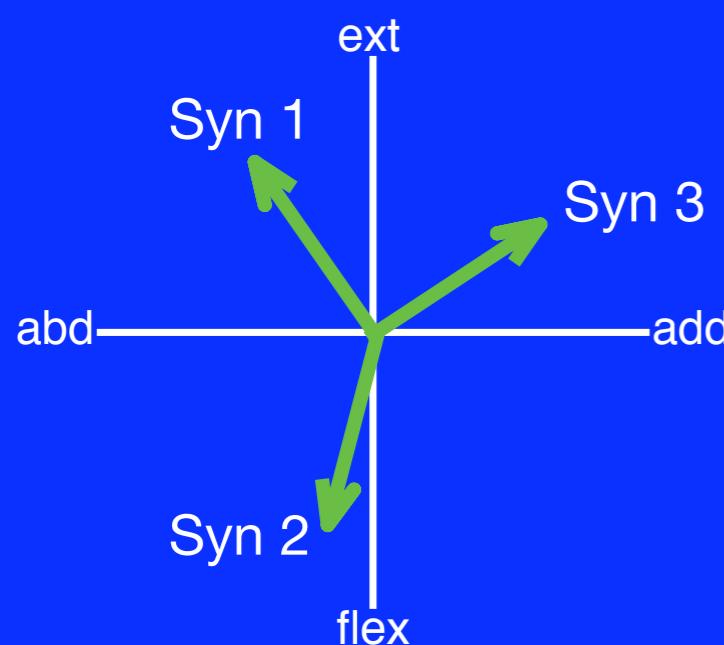
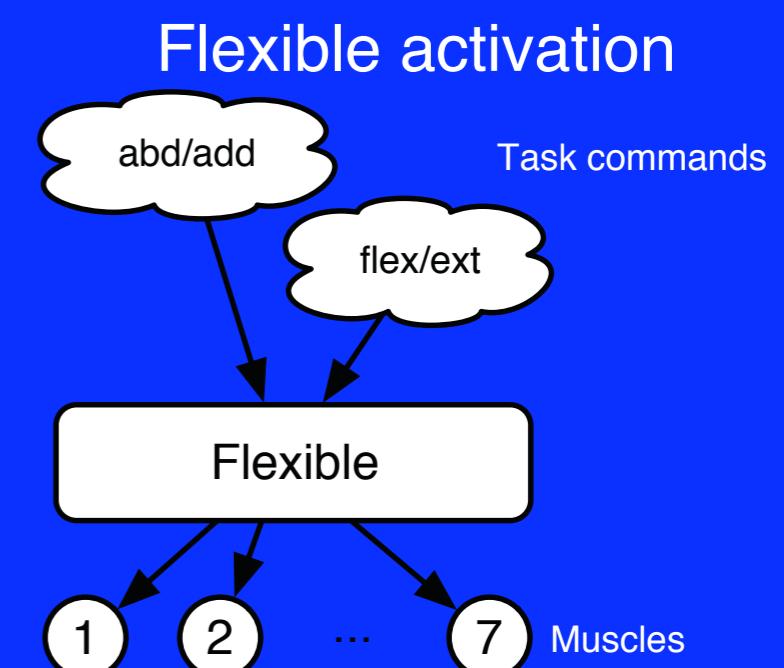
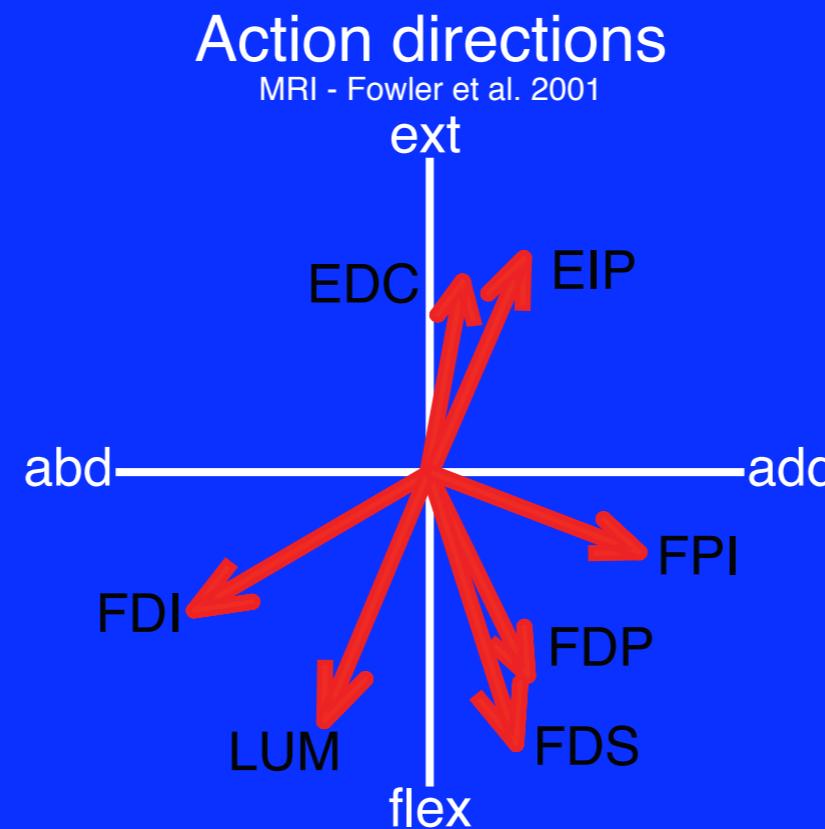
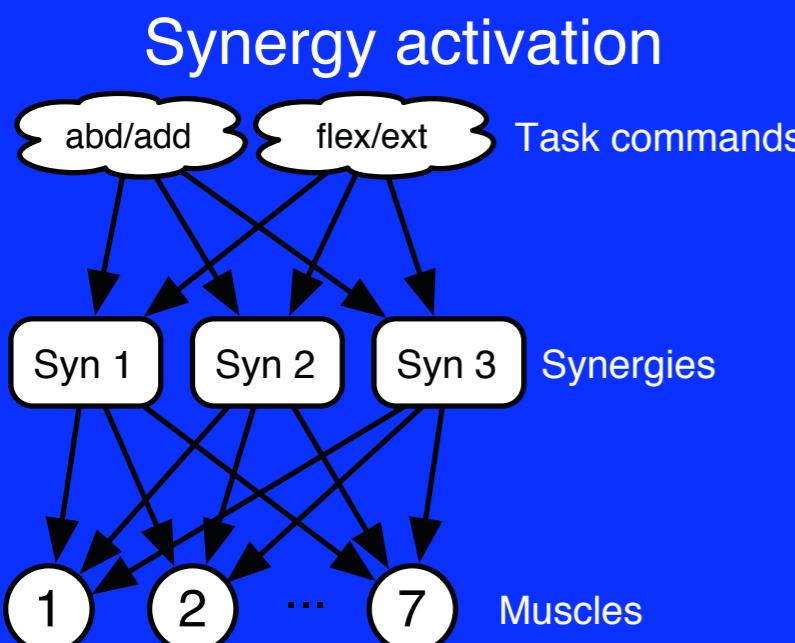
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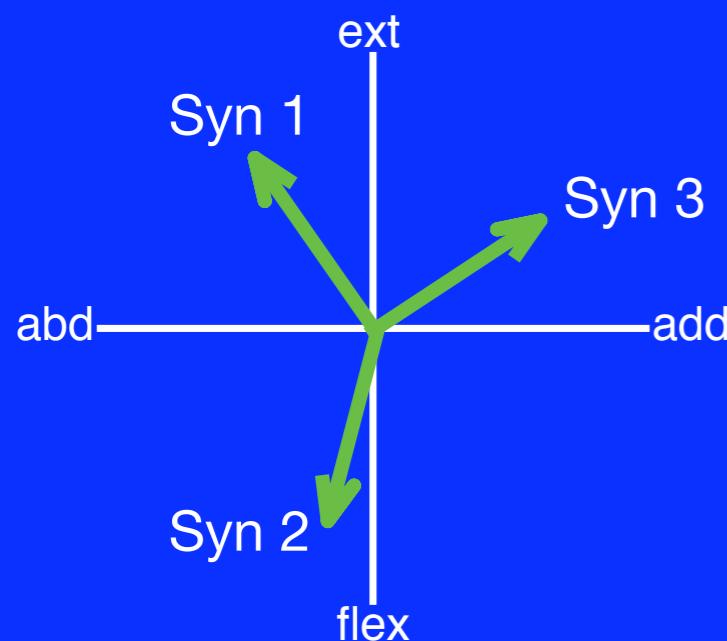
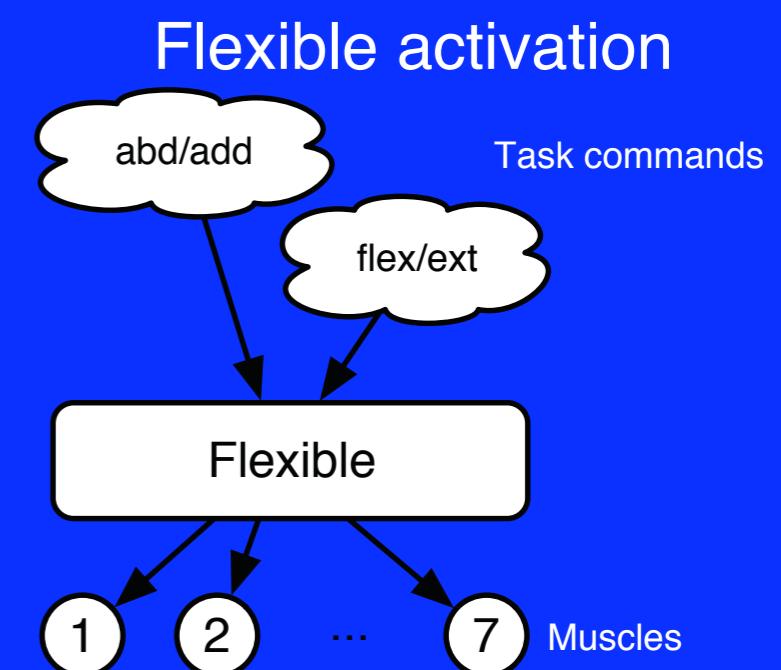
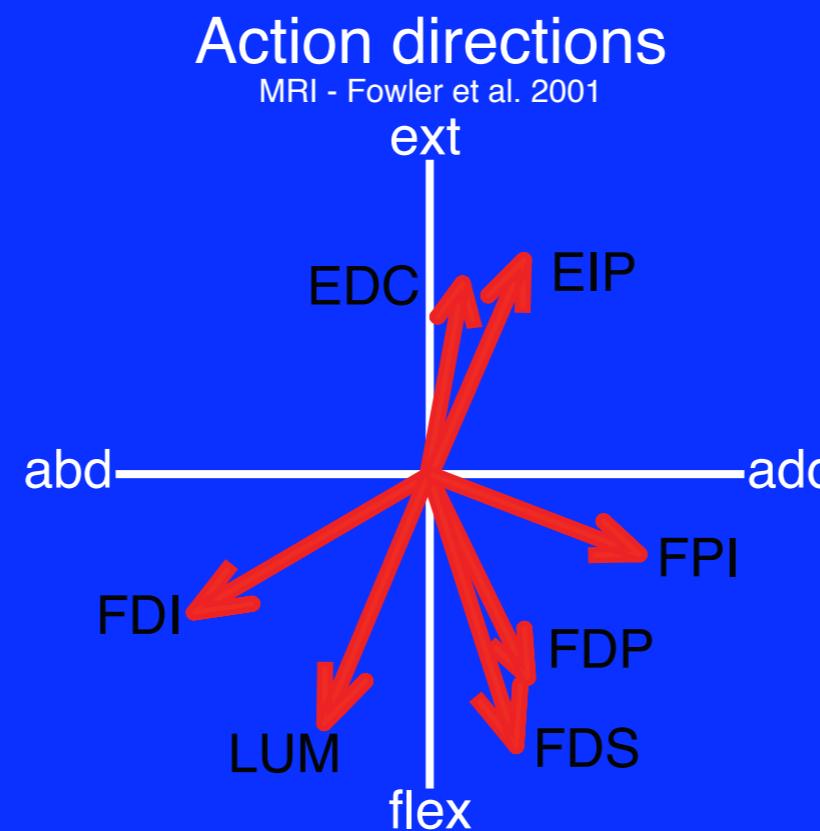
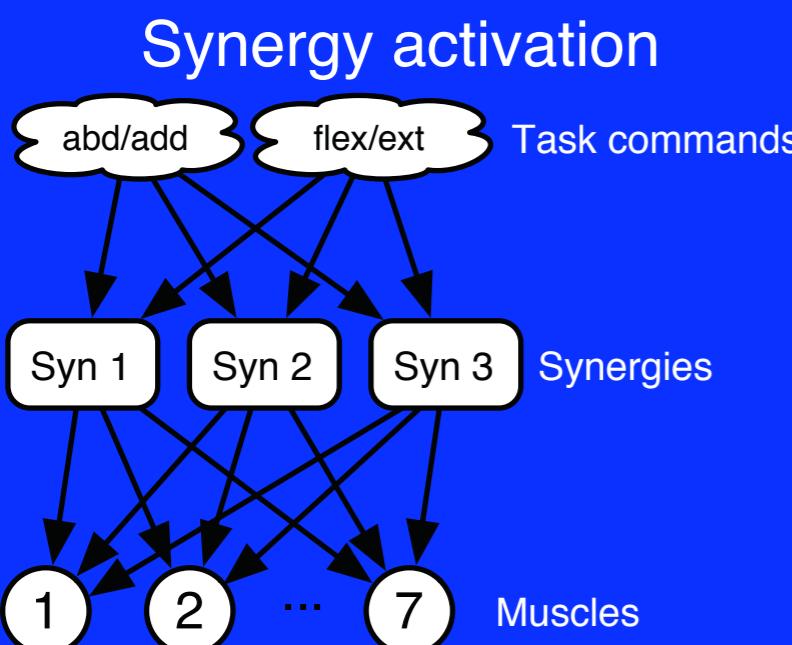
Task dimension determines output dimension



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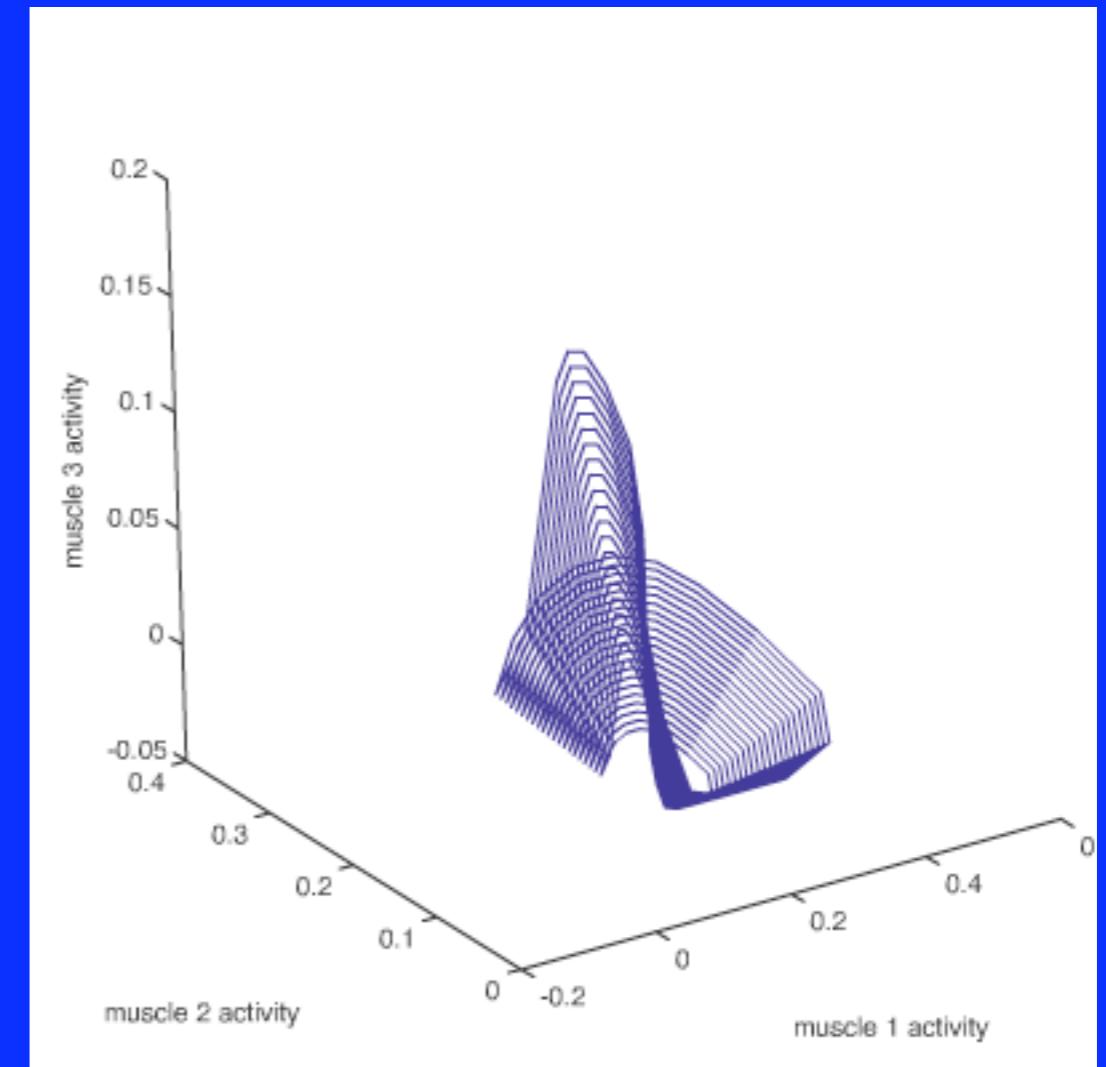
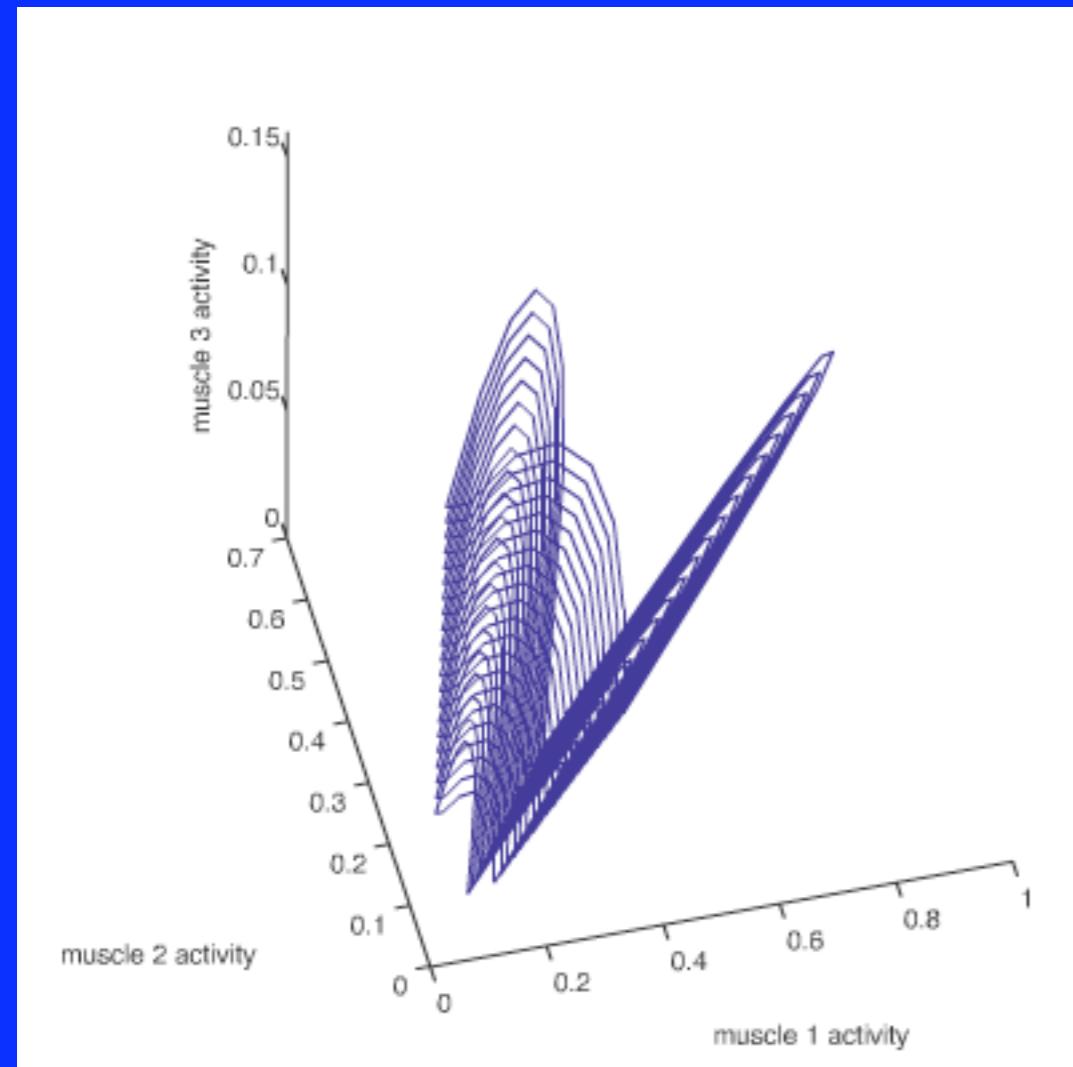
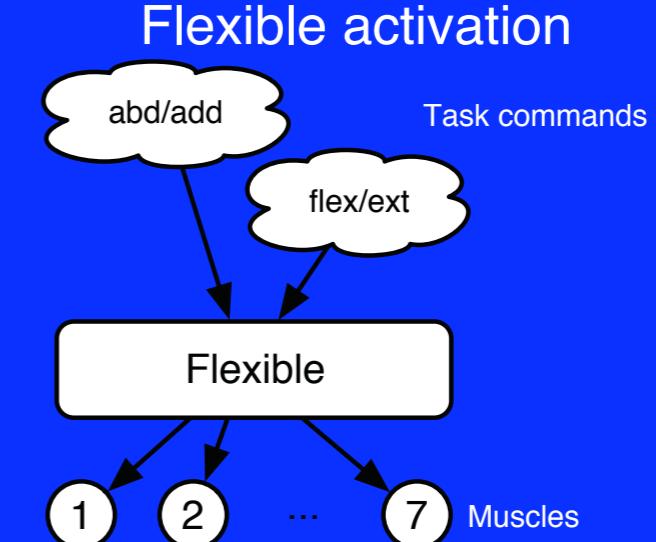
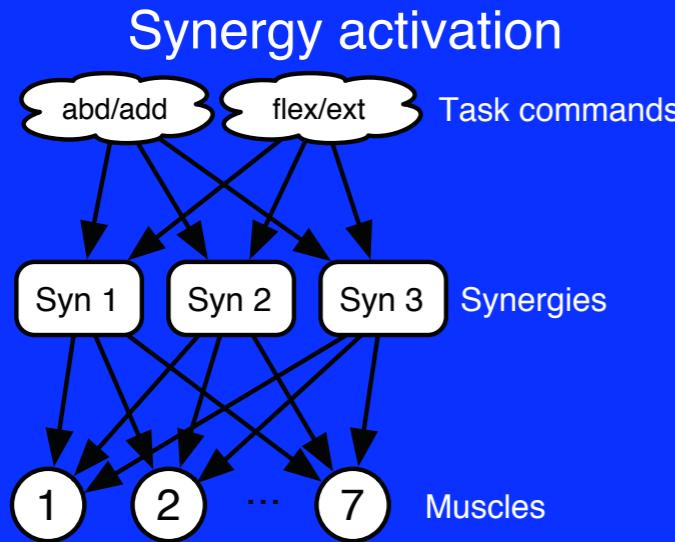
Task dimension determines output dimension



Minimize
total activity

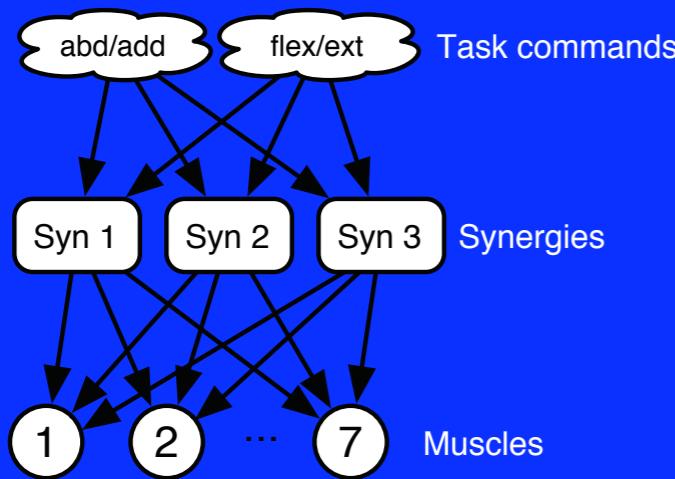
Dimensionality may not capture neural constraints

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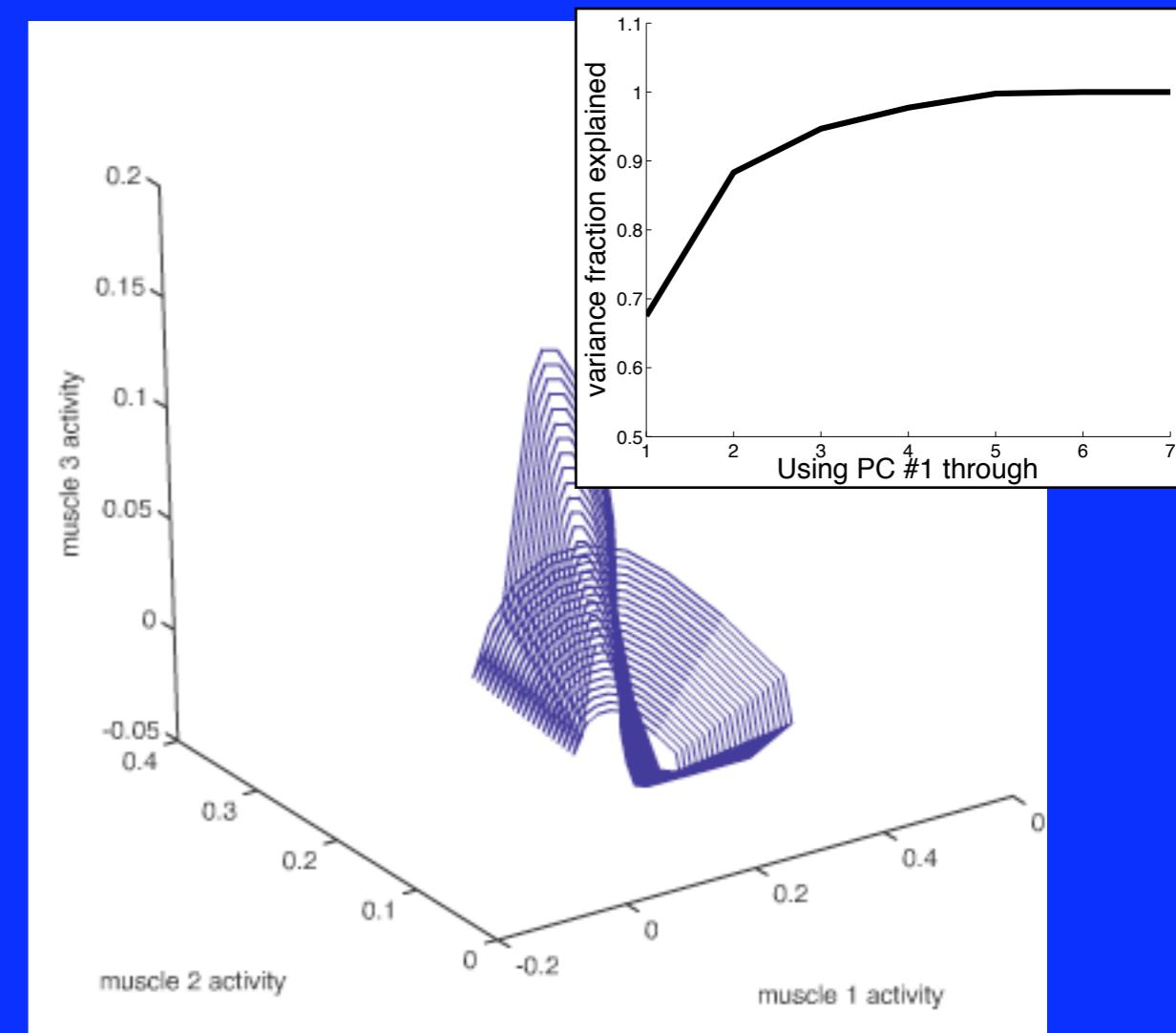
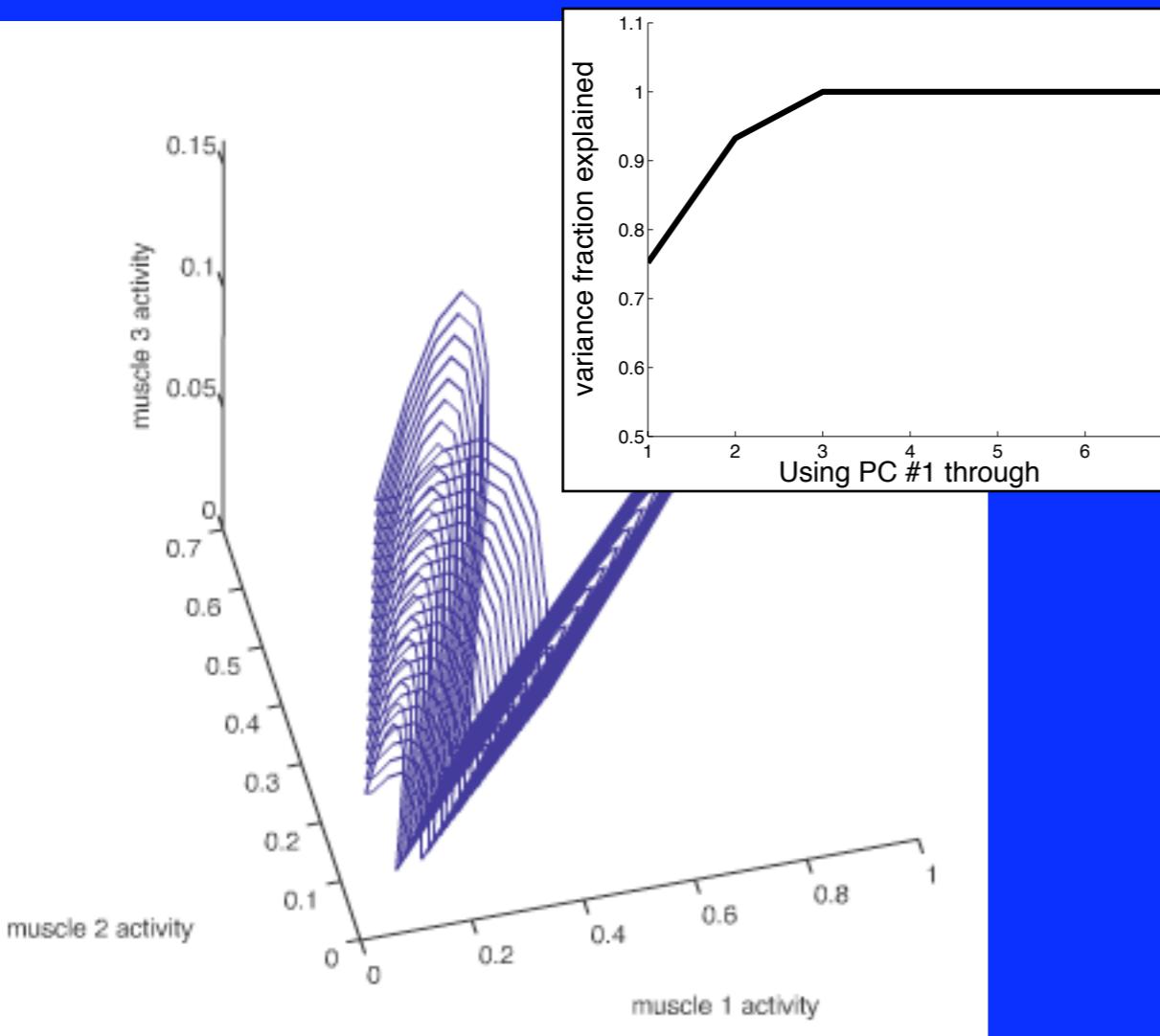
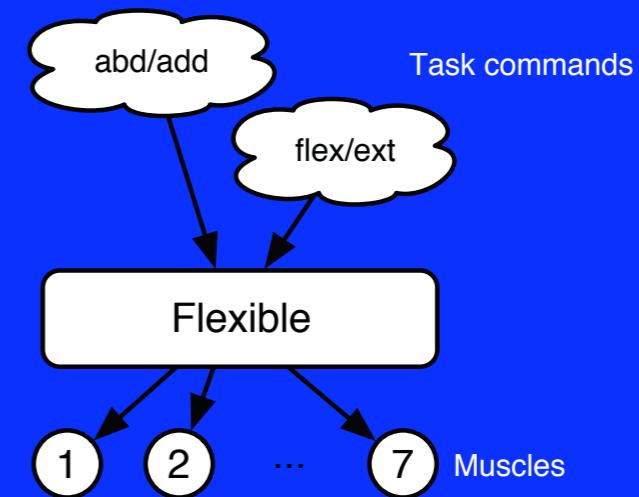


Dimensionality may not capture neural constraints

Synergy activation



Flexible activation

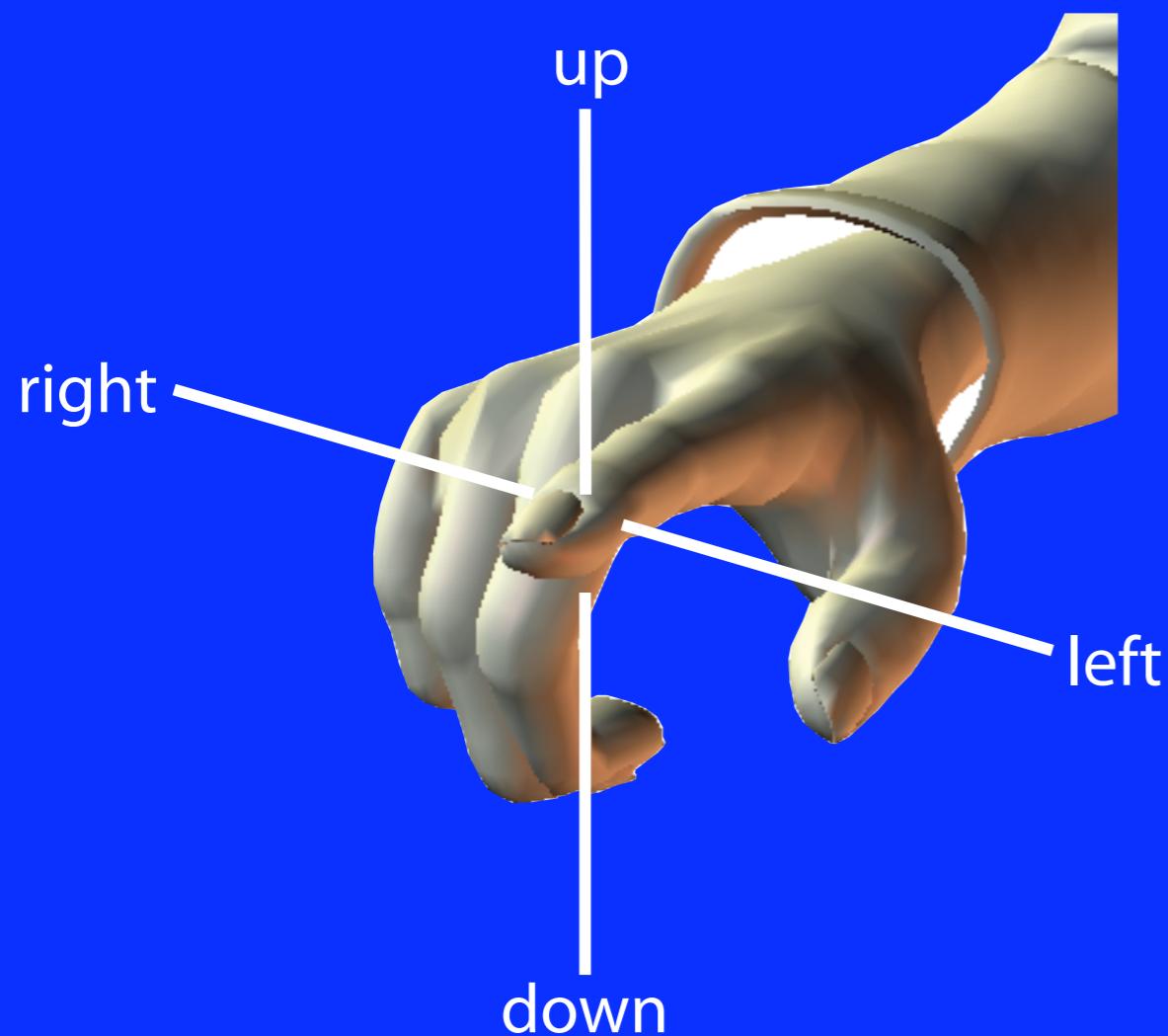


Circumventing task dimension with force variability



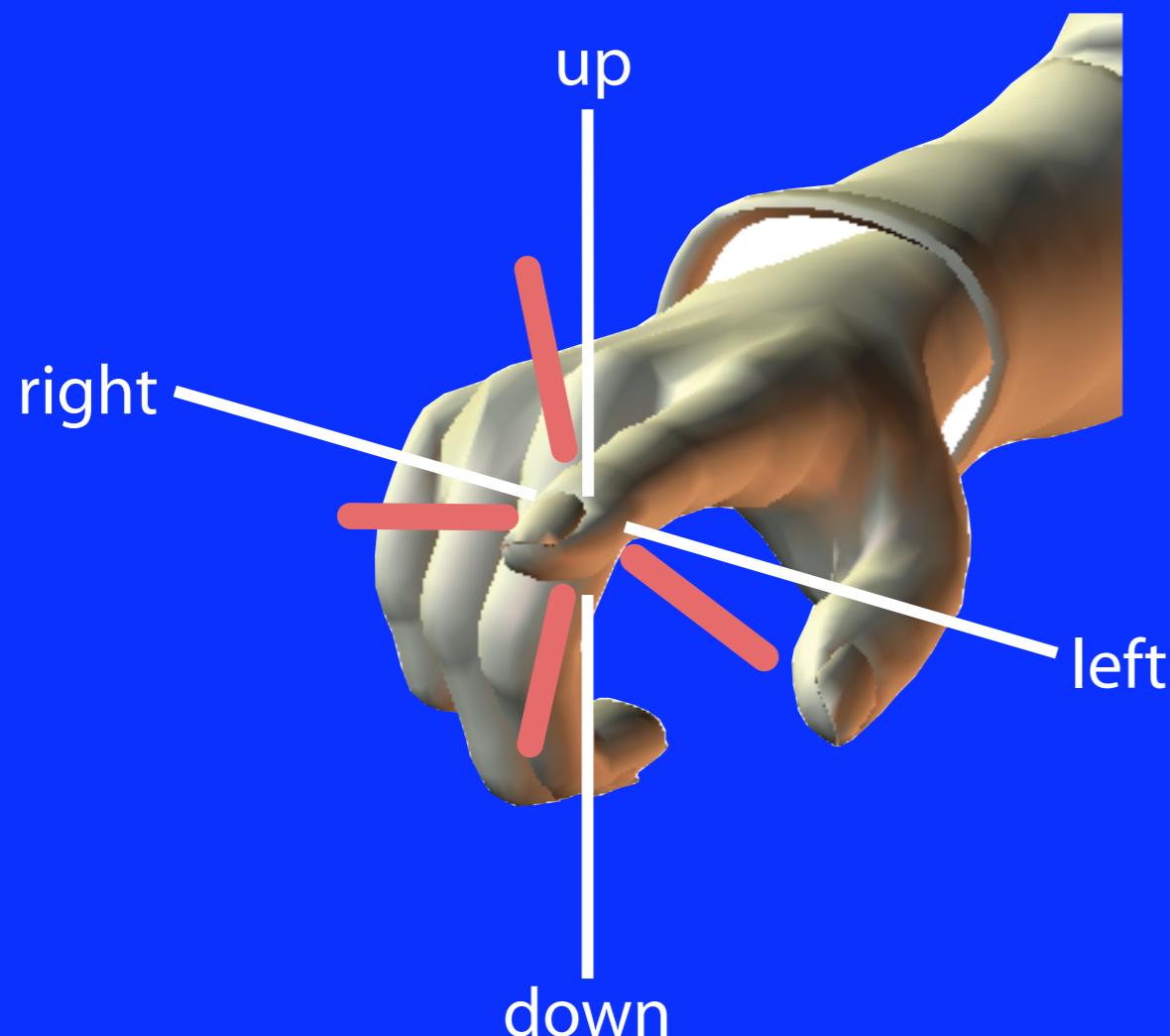
- Endpoint

Circumventing task dimension with force variability



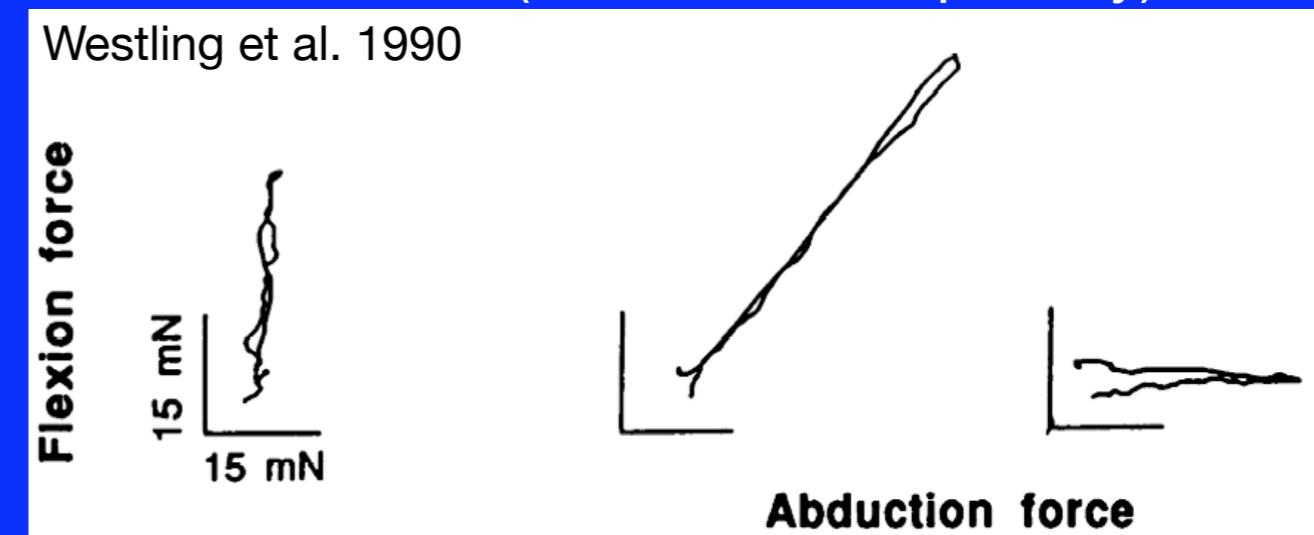
- Endpoint
- Task space (what the endpoint can do)

Circumventing task dimension with force variability

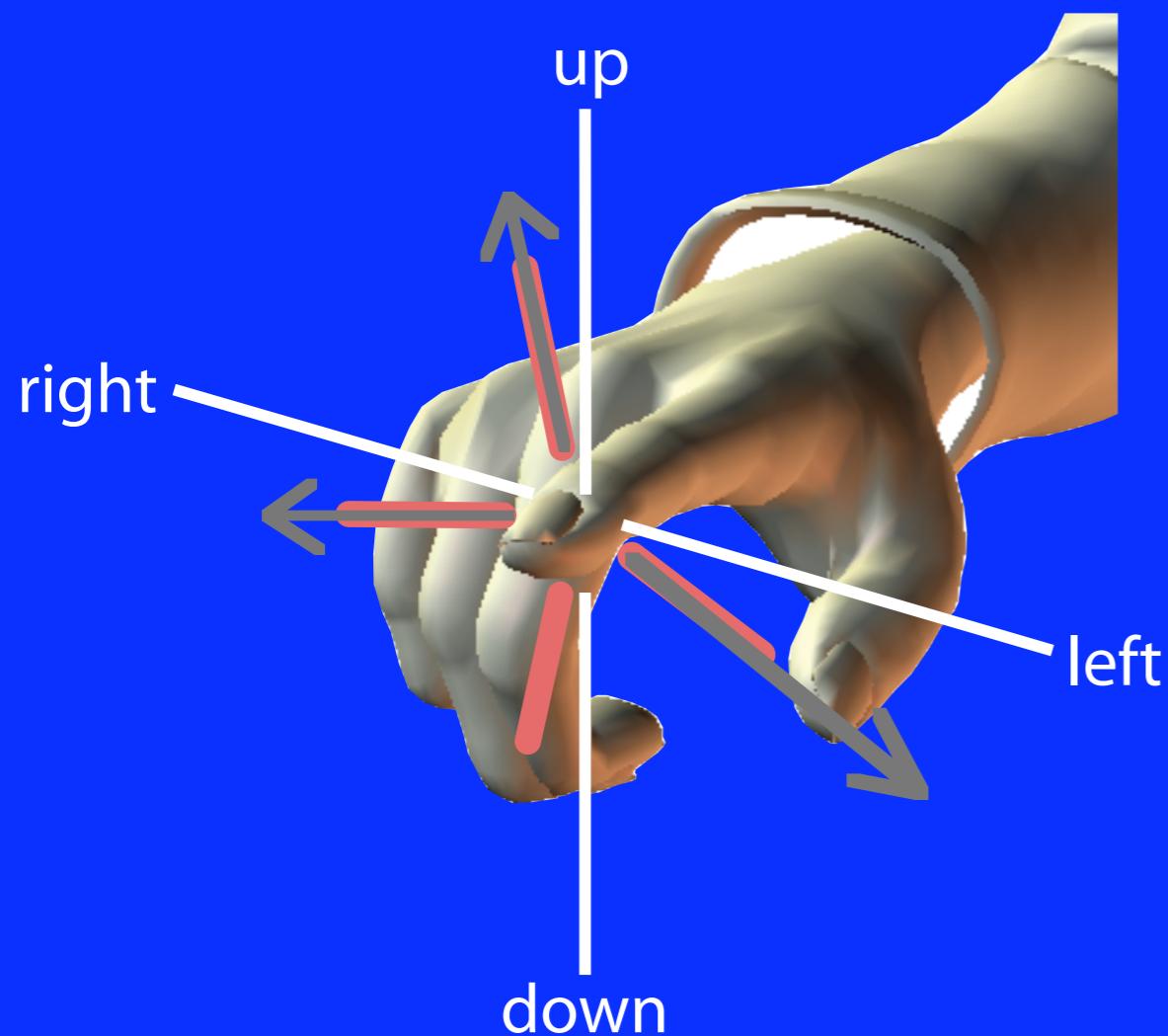


- Endpoint
- Task space (what the endpoint can do)
- Muscle action (direction of capability)

Westling et al. 1990

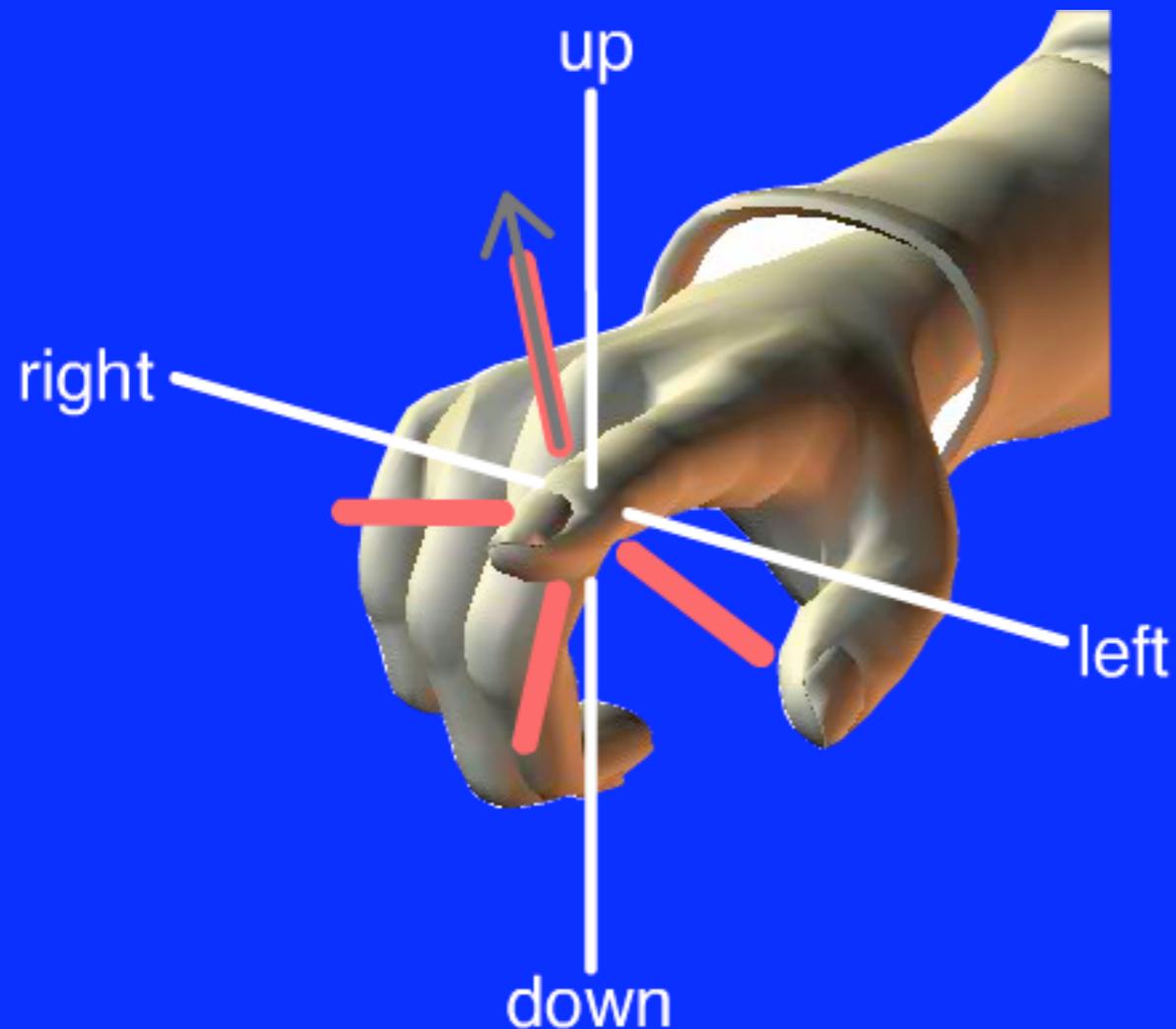


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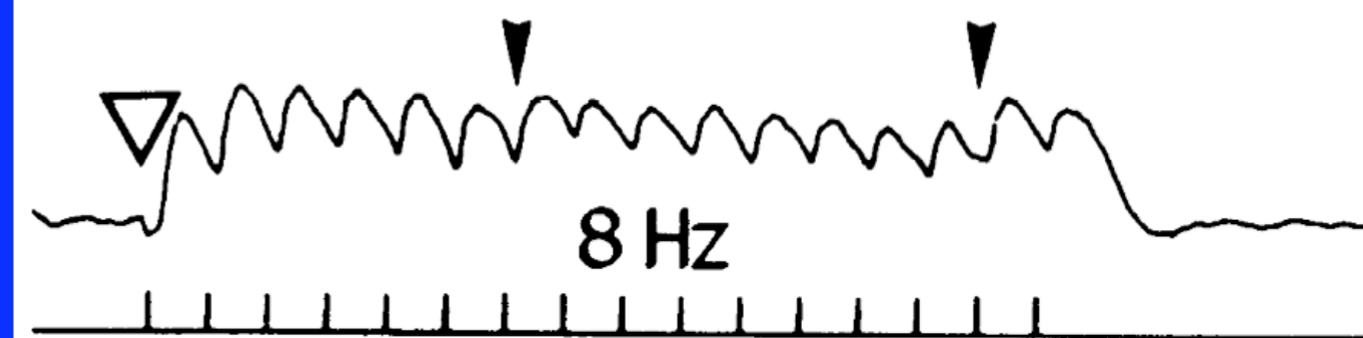
- Endpoint
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Circumventing task dimension with force variability

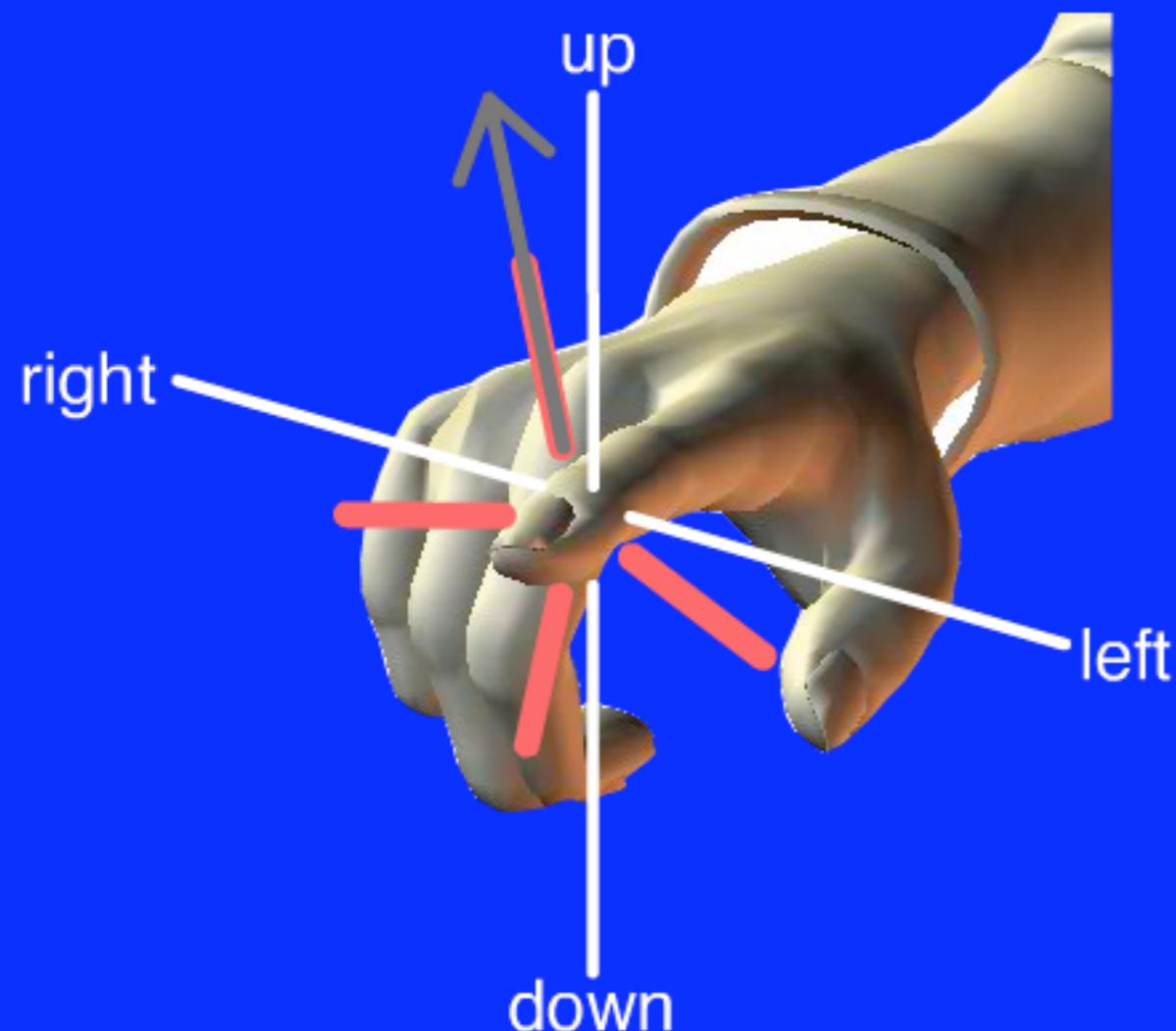


- Endpoint
- Task space (what the endpoint can do)
- Muscle action (direction of capability)
- Muscle endpoint vector (force applied)
- Signal-dependent noise
(more fluctuation for more force)

Thomas et al. 1991

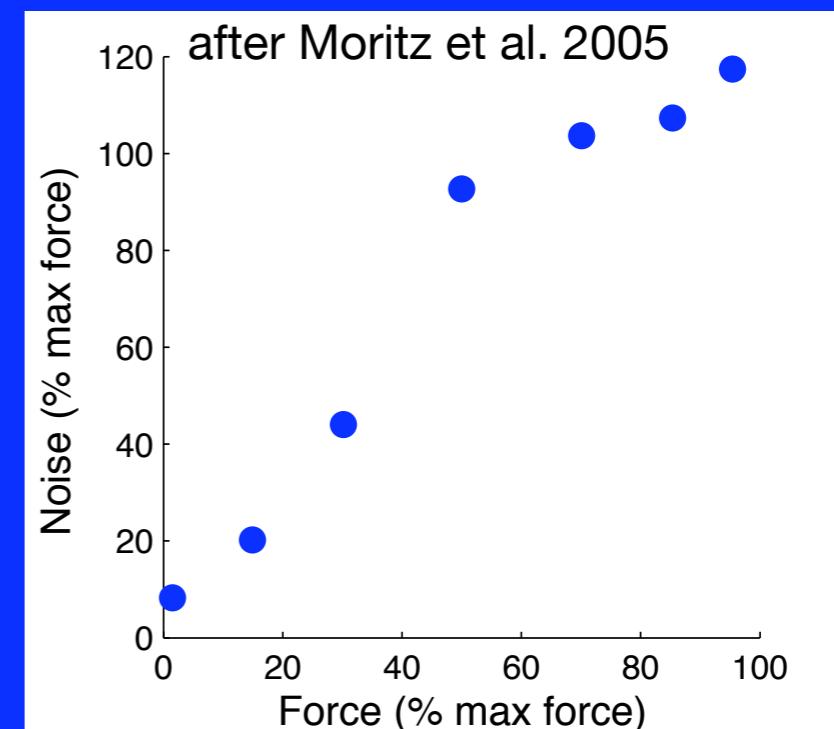
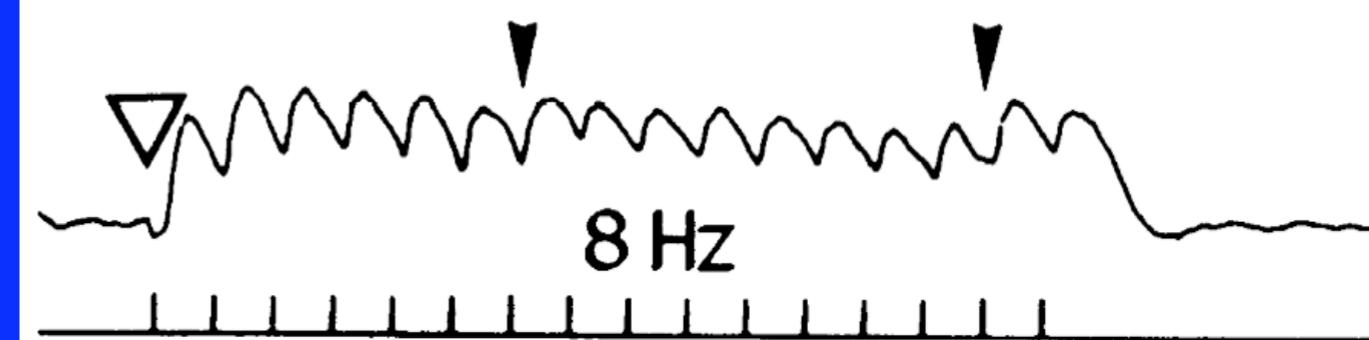


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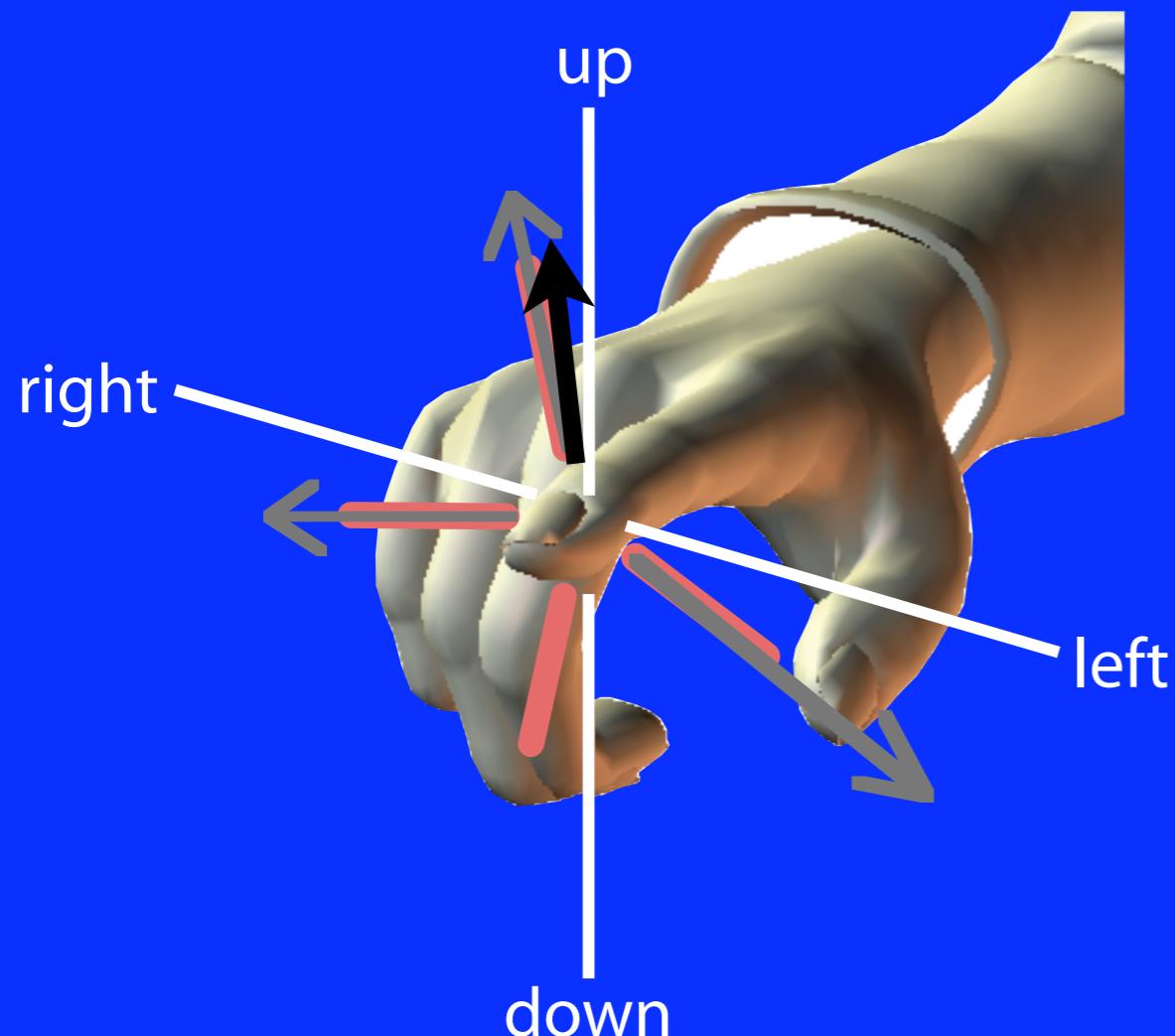


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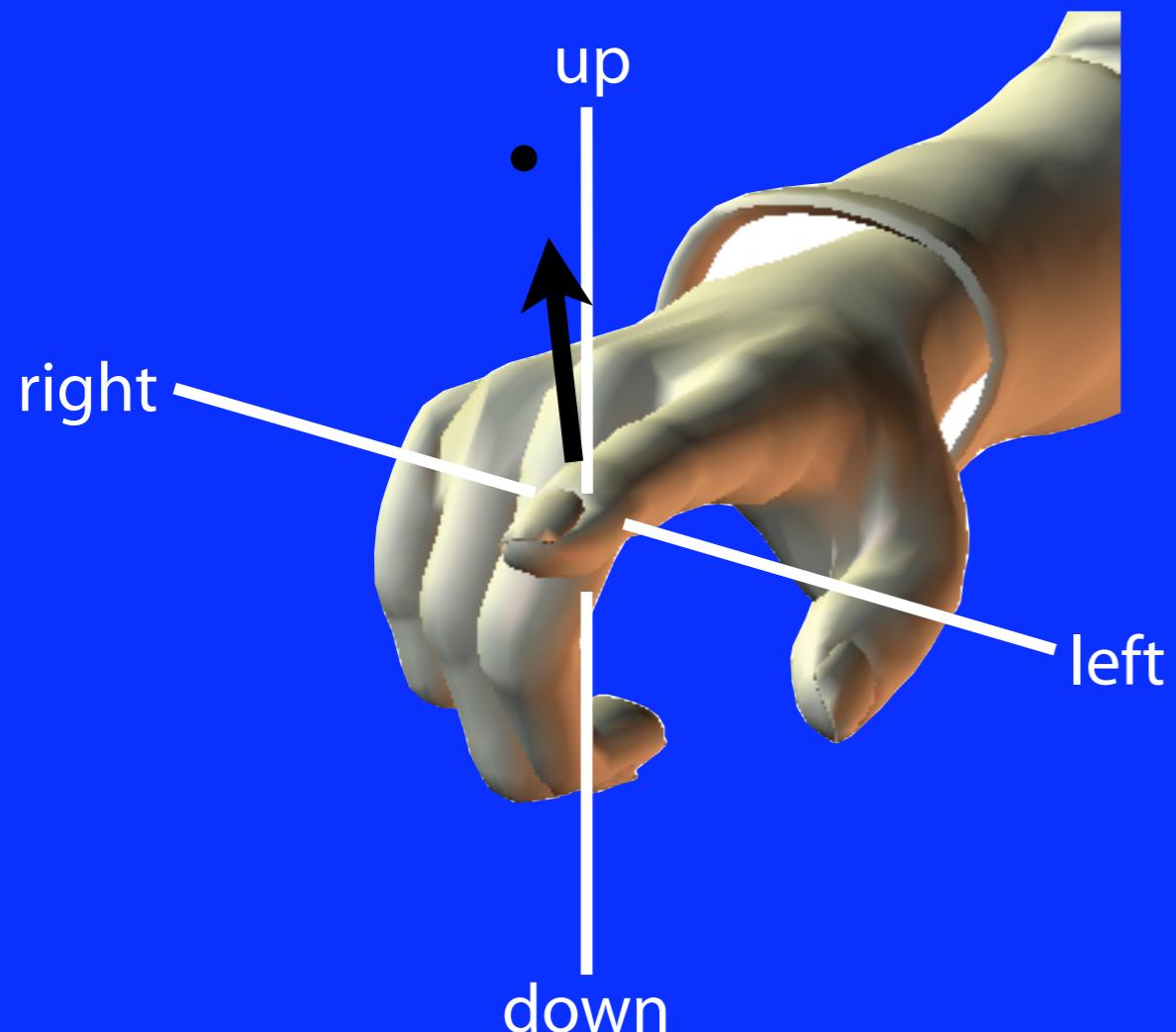


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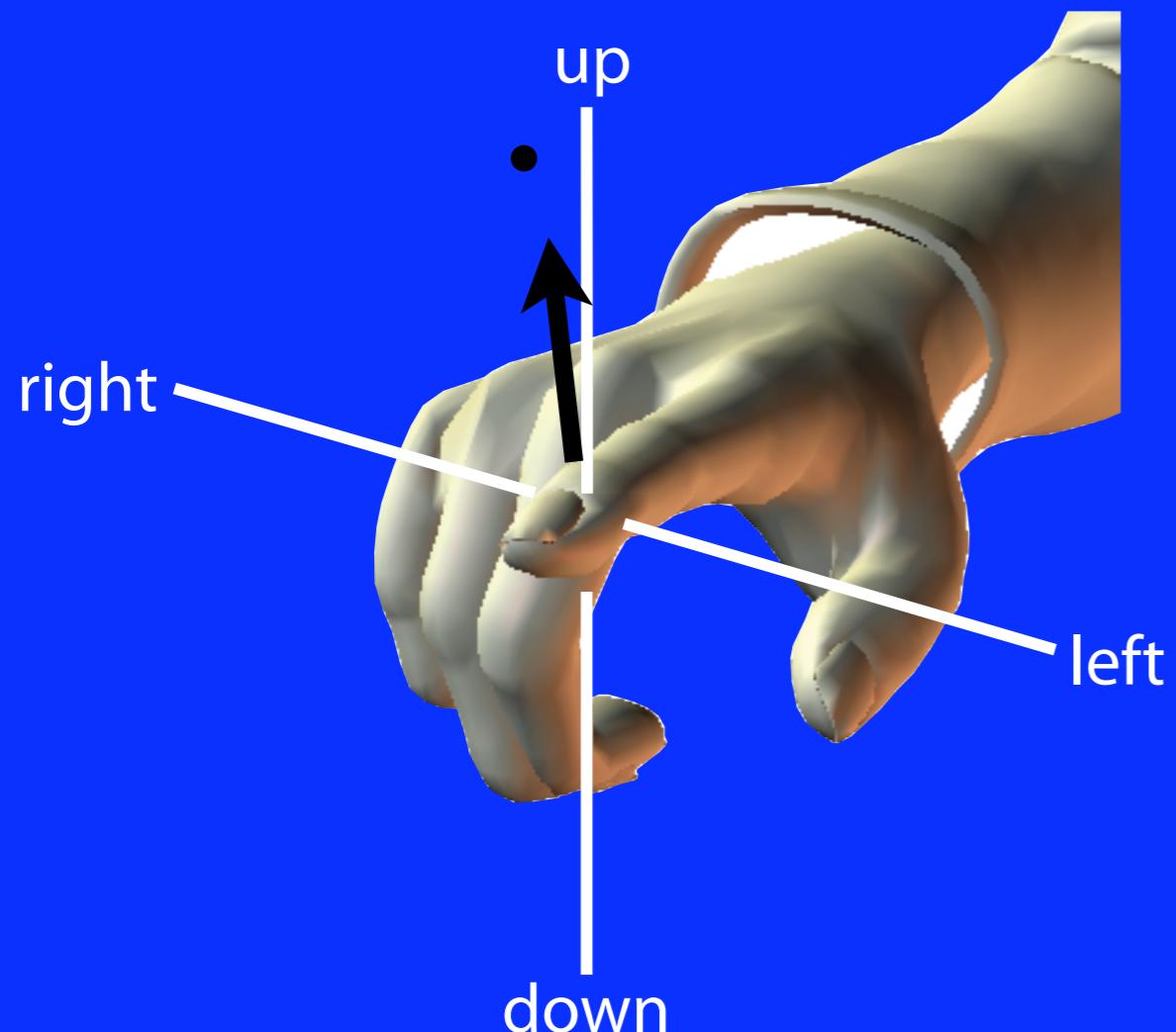
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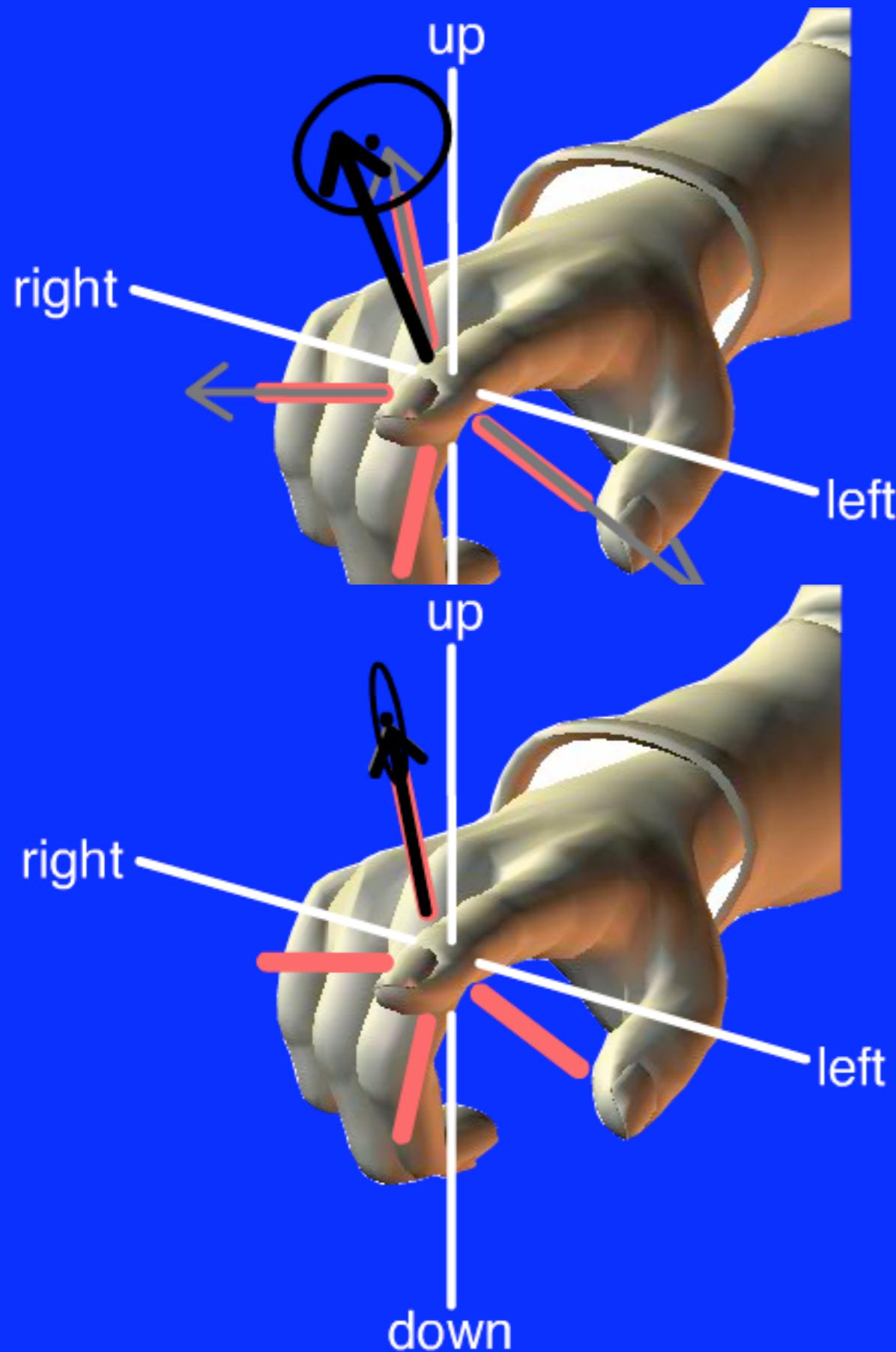
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New Concepts

Circumventing task dimension with force variability

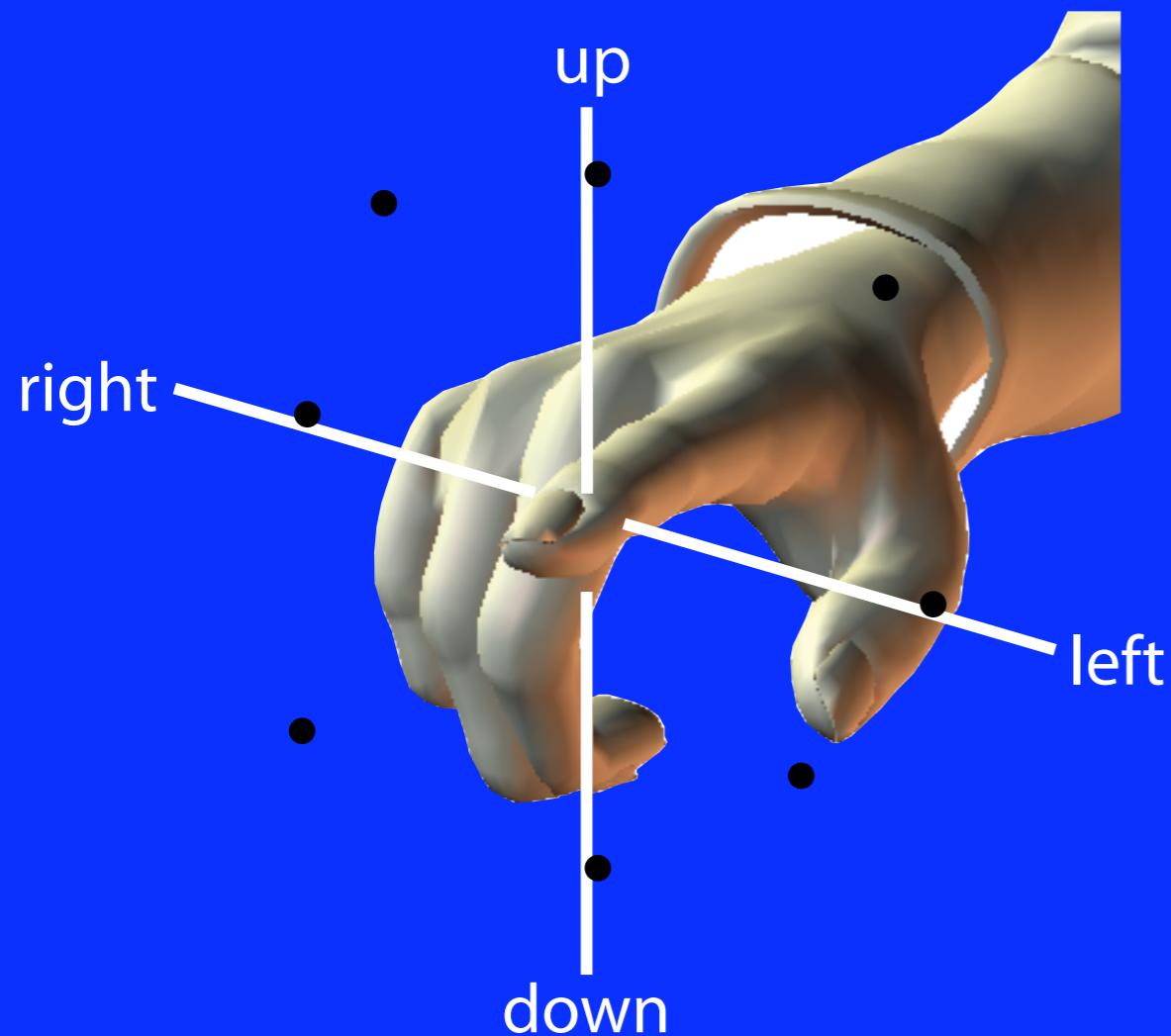


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New Concepts

- Non-directed ellipse (multiple muscle)
- Directed ellipse (primary muscle)

Circumventing task dimension with force variability

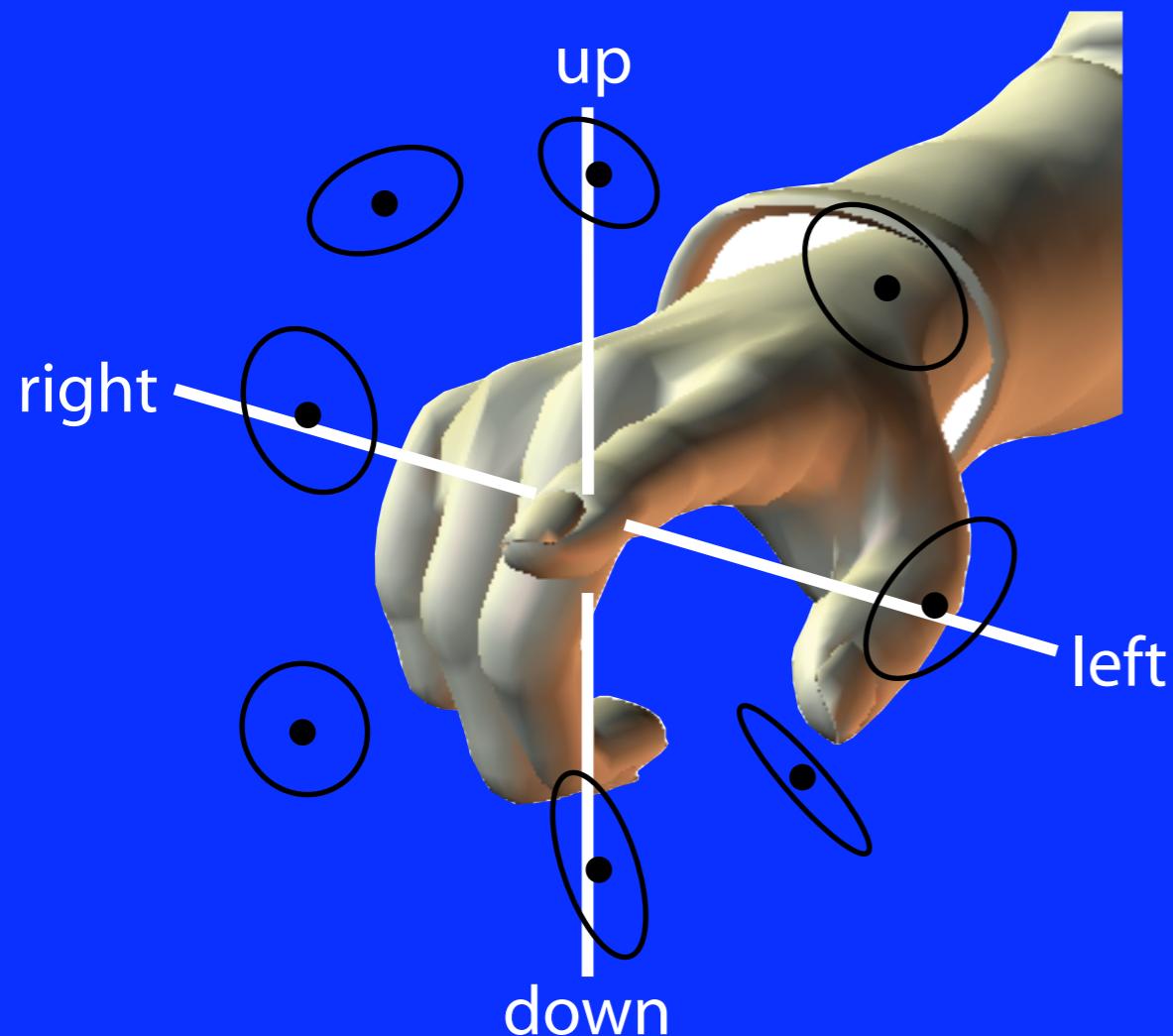


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Circumventing task dimension with force variability

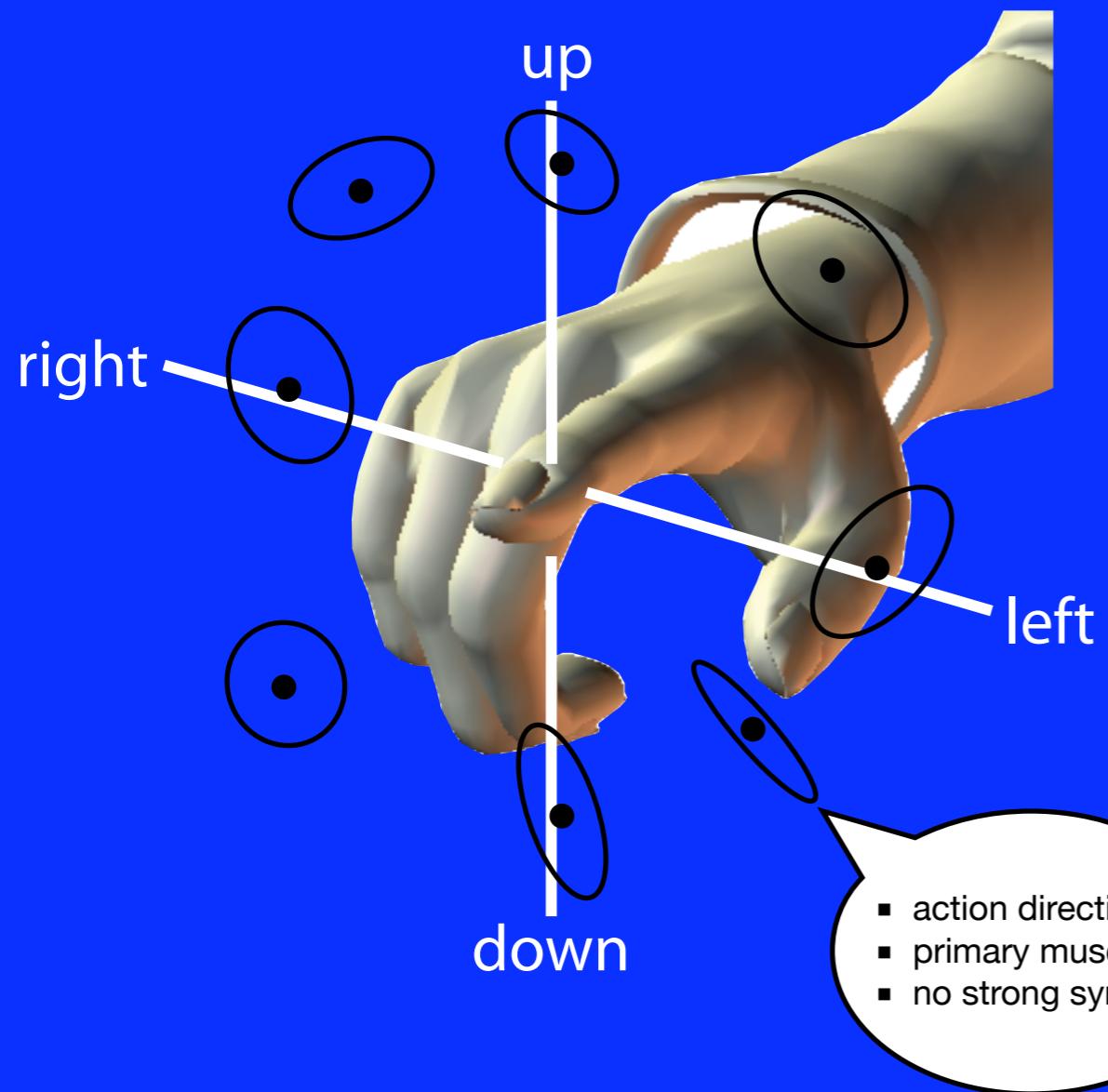


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- *Force Covariance Map (FCM)*

Circumventing task dimension with force variability



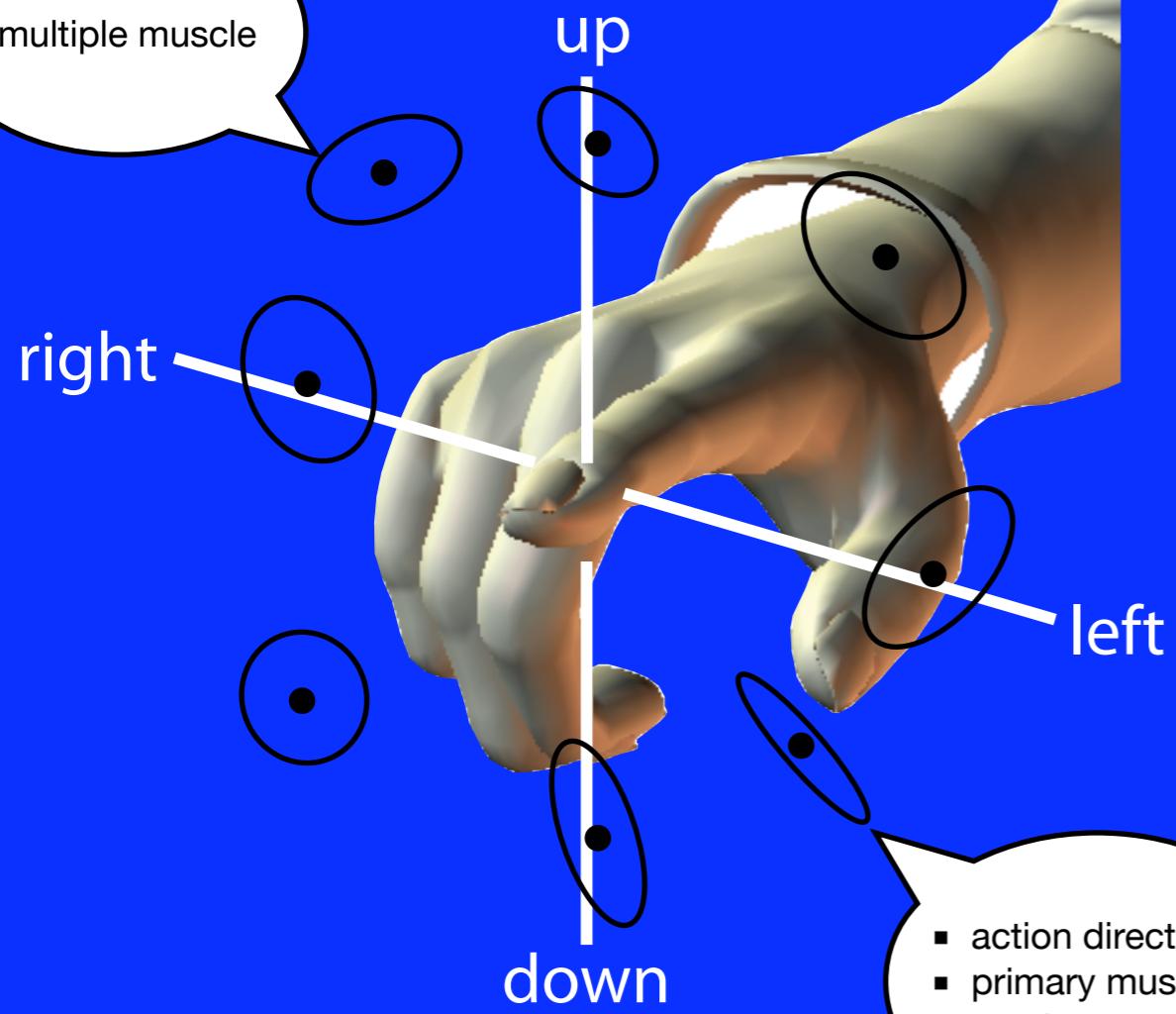
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Circumventing task dimension with force variability

- multiple muscle



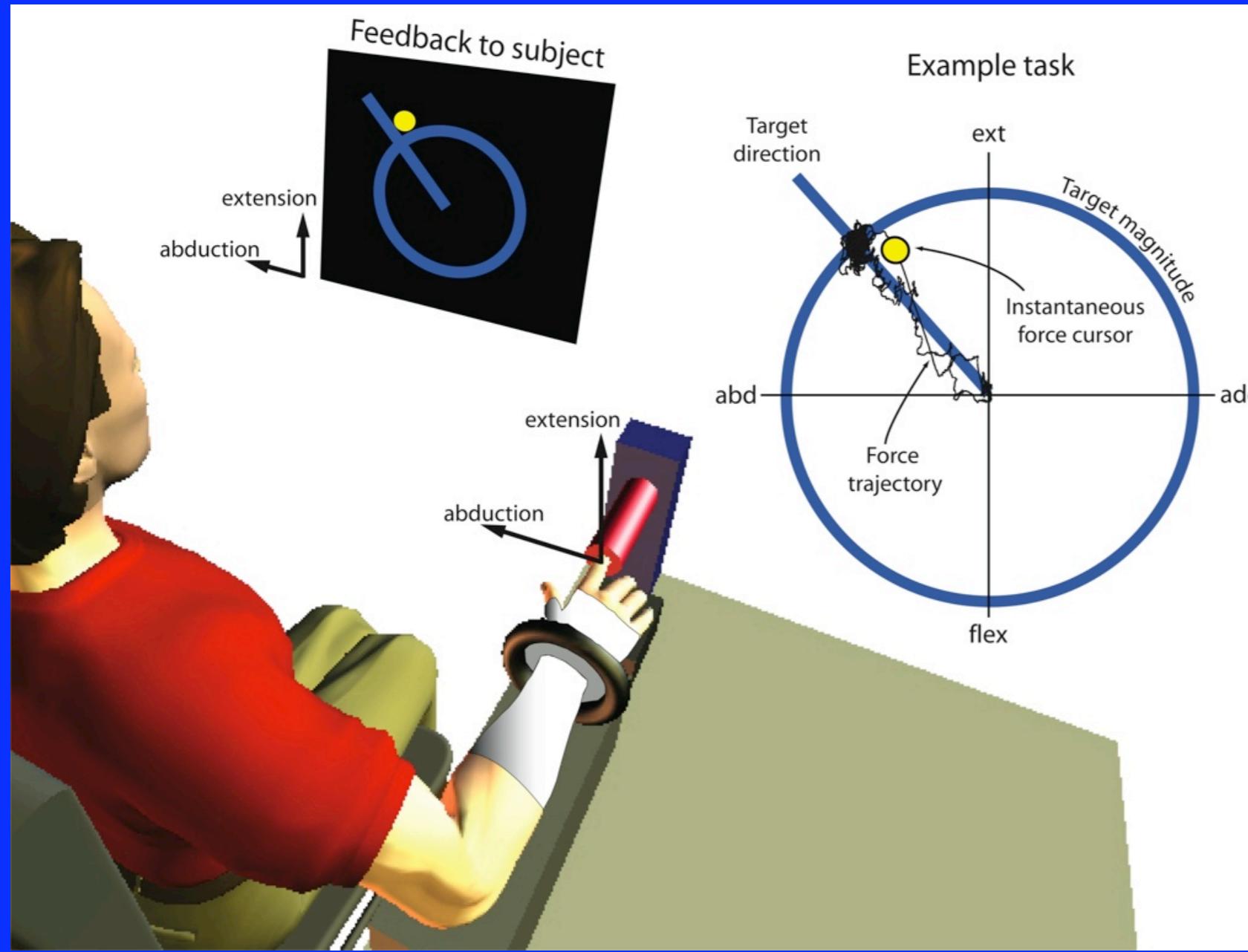
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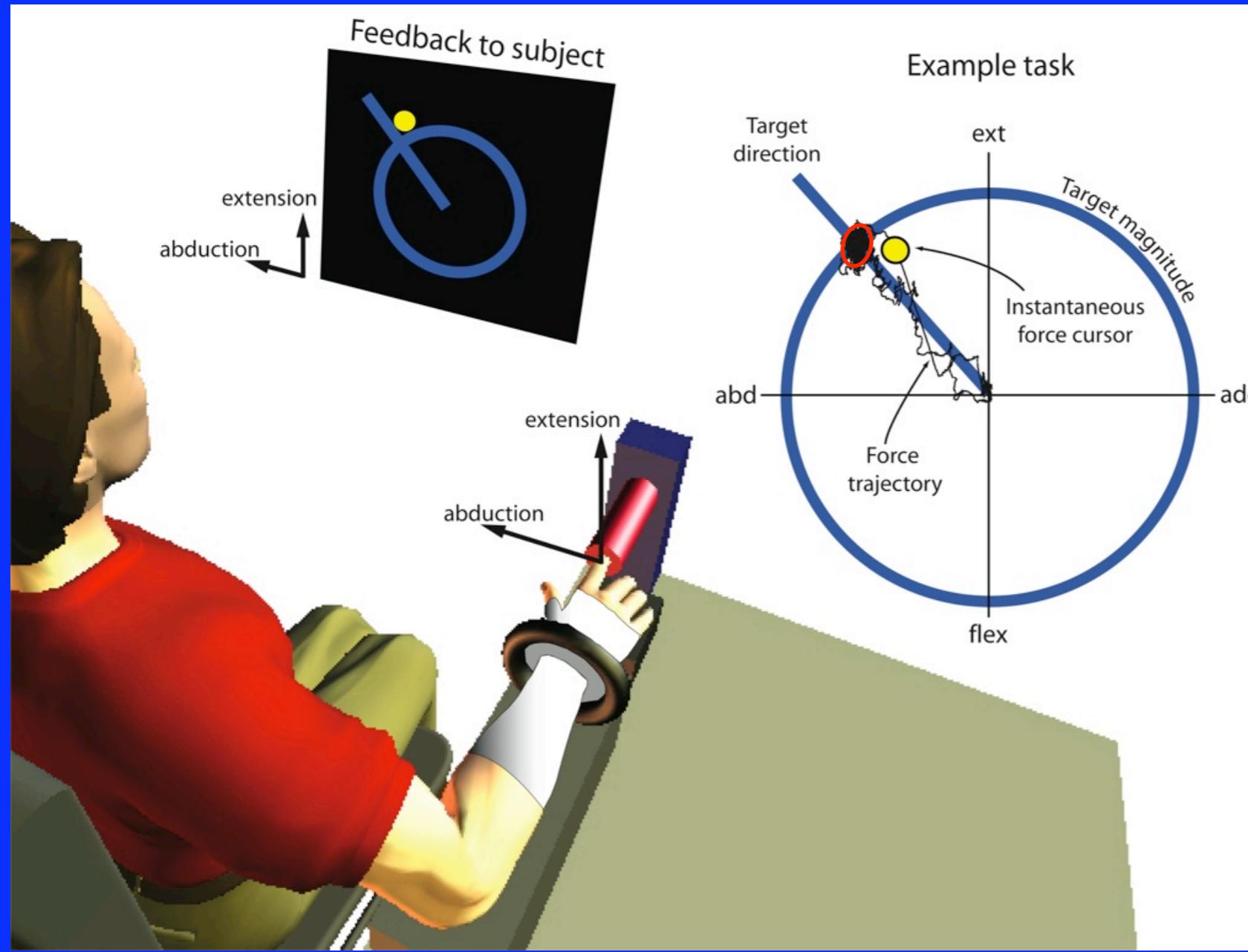
- Non-directed ellipse (multiple muscle)
- Directed ellipse (primary muscle)
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- *Force Covariance Map (FCM)*

Force covariance mapping: experimental setup

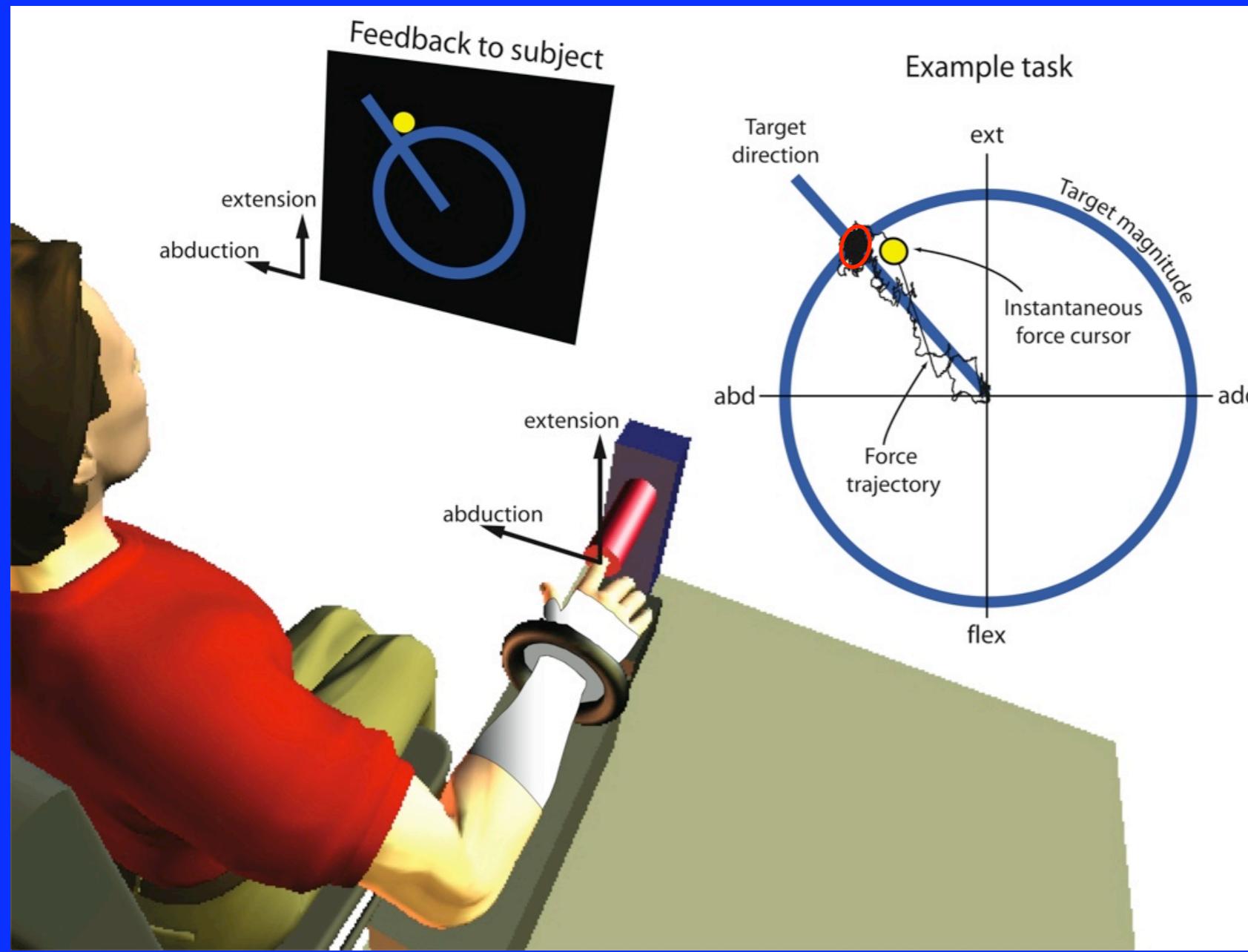
Force covariance mapping: experimental setup



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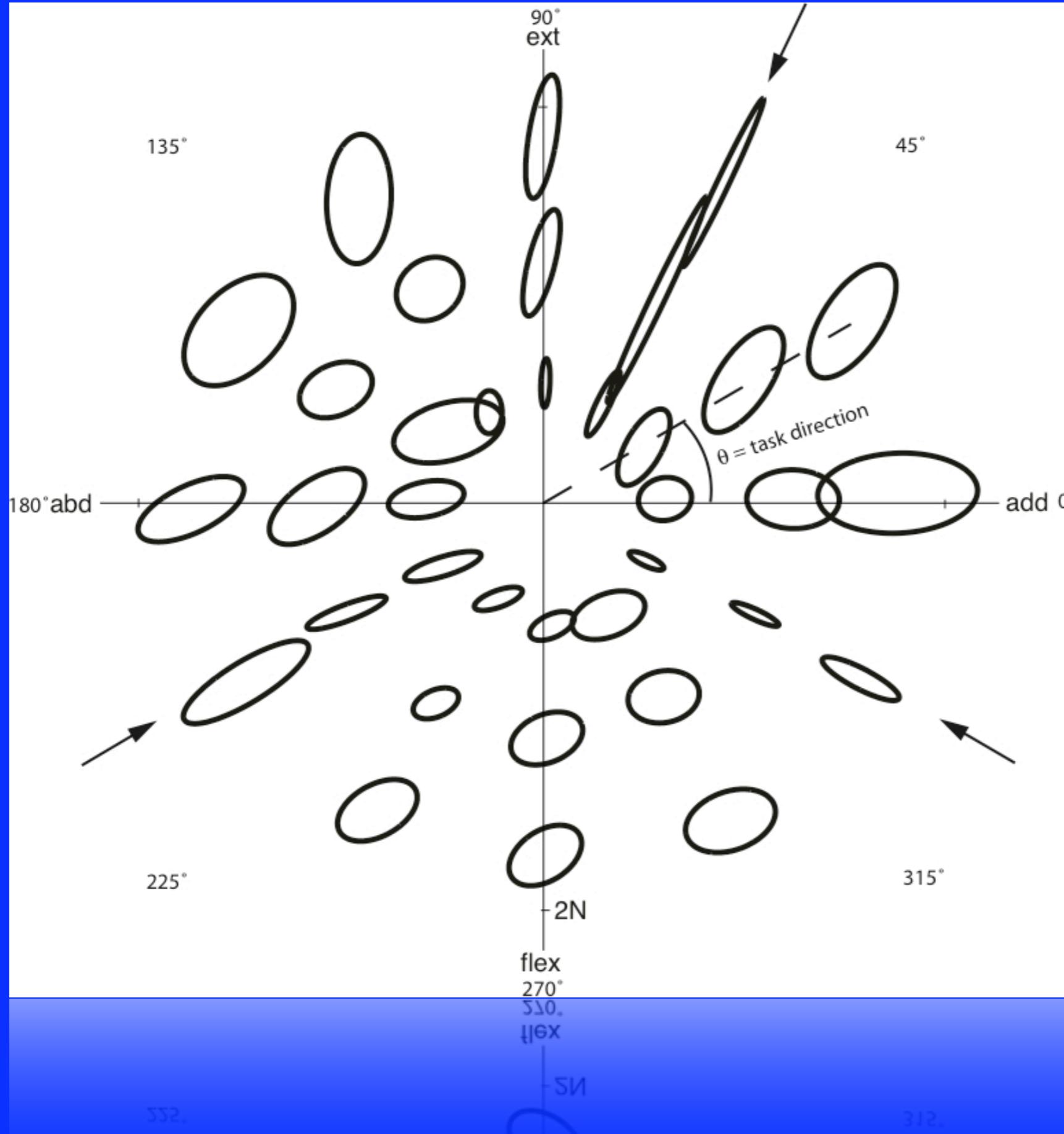


Details:

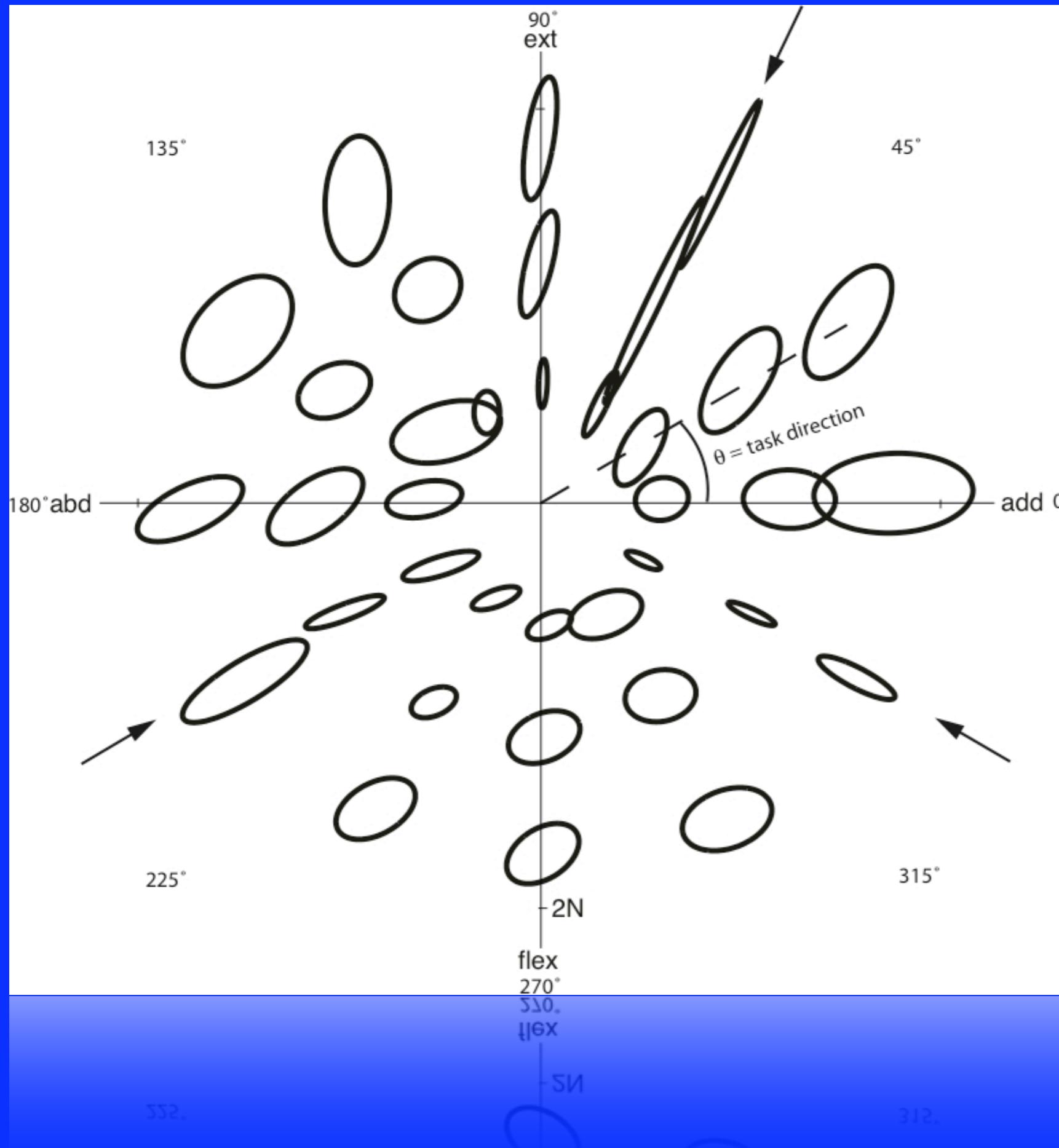
1. Load cell (JR3, Woodland, CA) has 1 mN smallest measurable load
2. Load amplified using lightweight aluminum tube
3. Low electrical noise environment
4. Table vibration minimized
5. Surface EMG measured using silver electrodes with self-contained preamplifiers (Delsys, Boston, MA)
6. Subject's given a target and a force cursor
7. Targets span plane with radial grid

Force covariance mapping: representative results

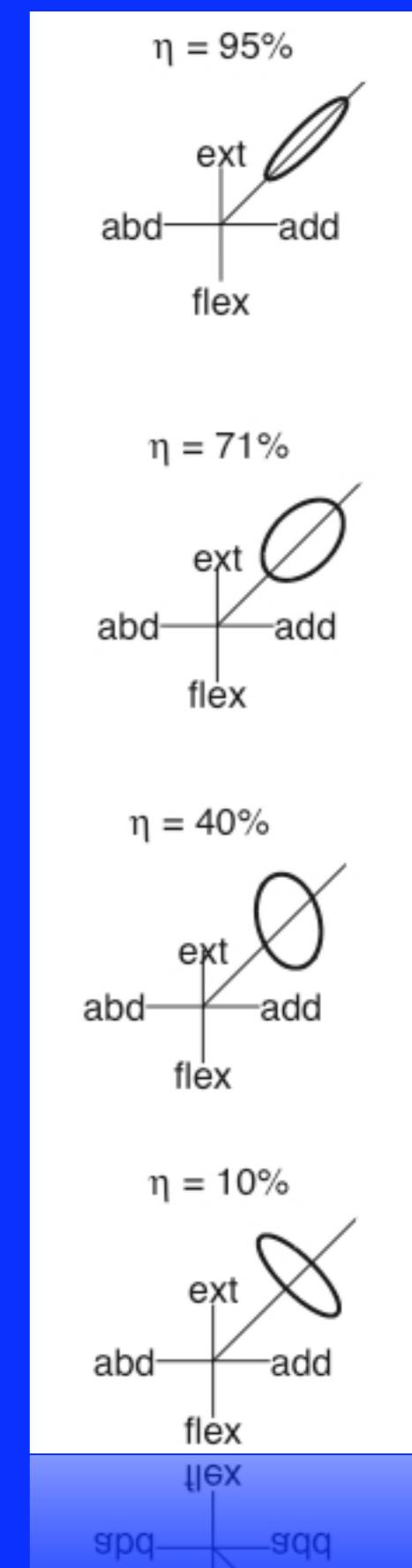
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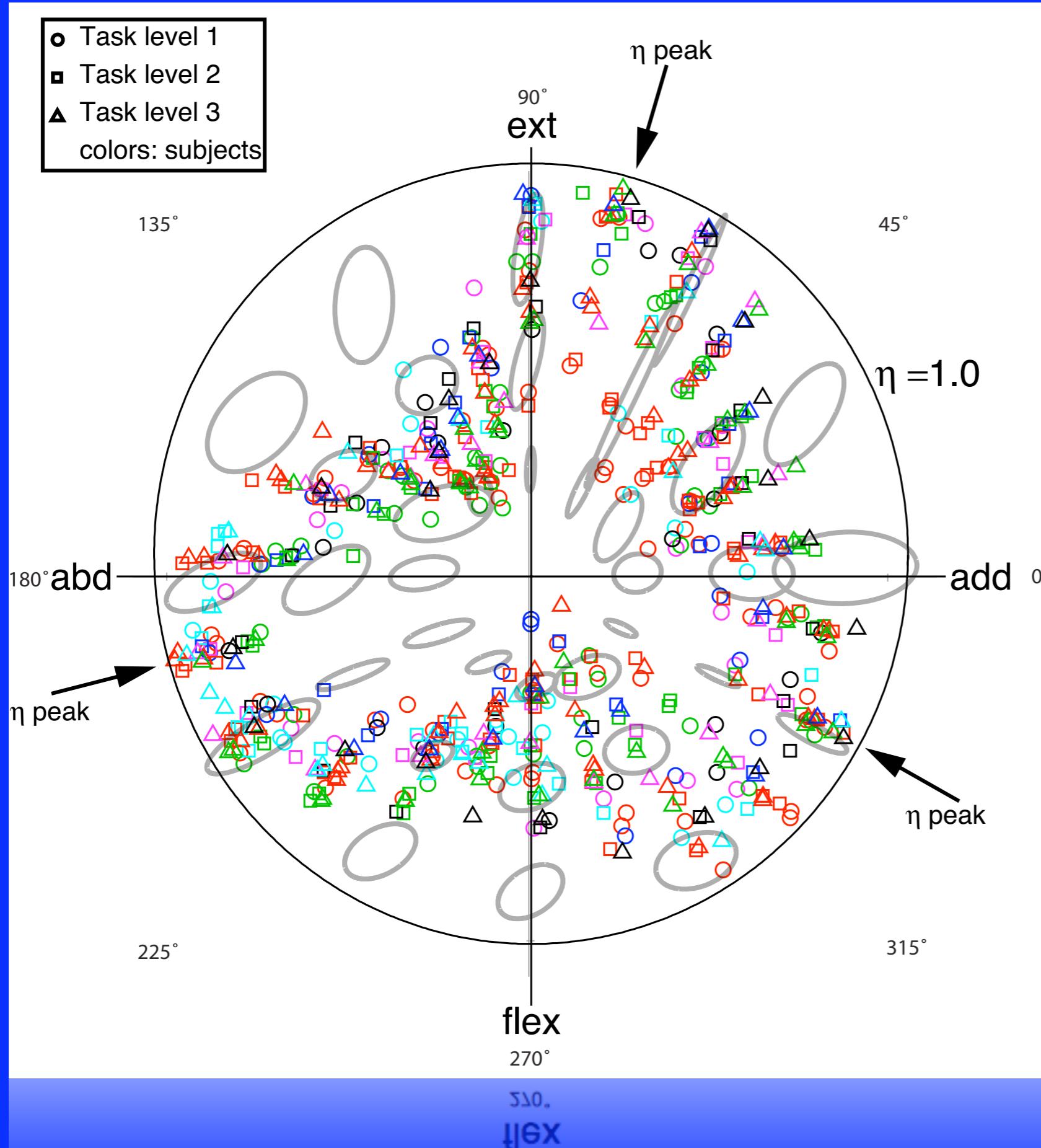


Task-directed variance fraction

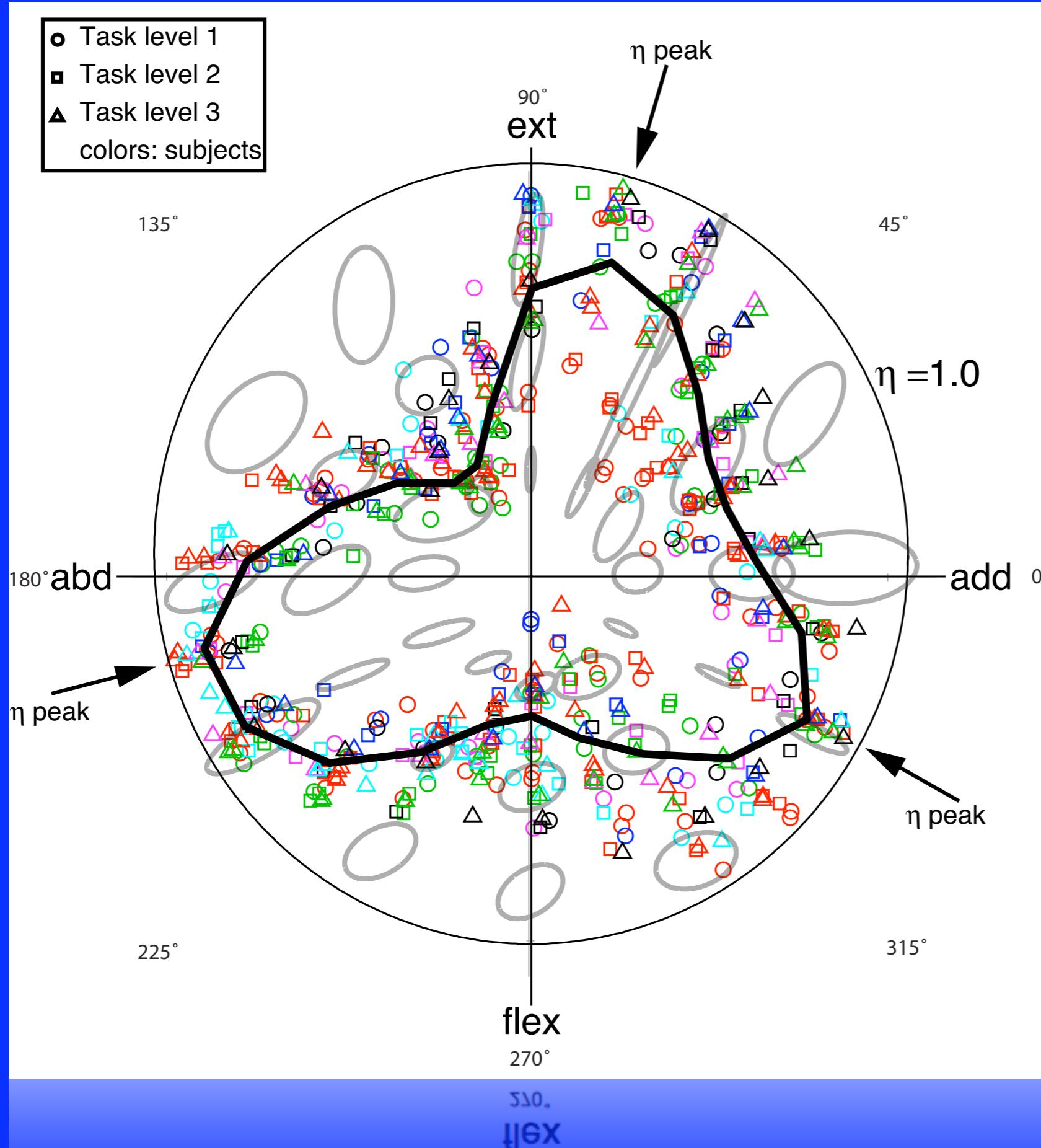


Force covariance mapping: entire dataset

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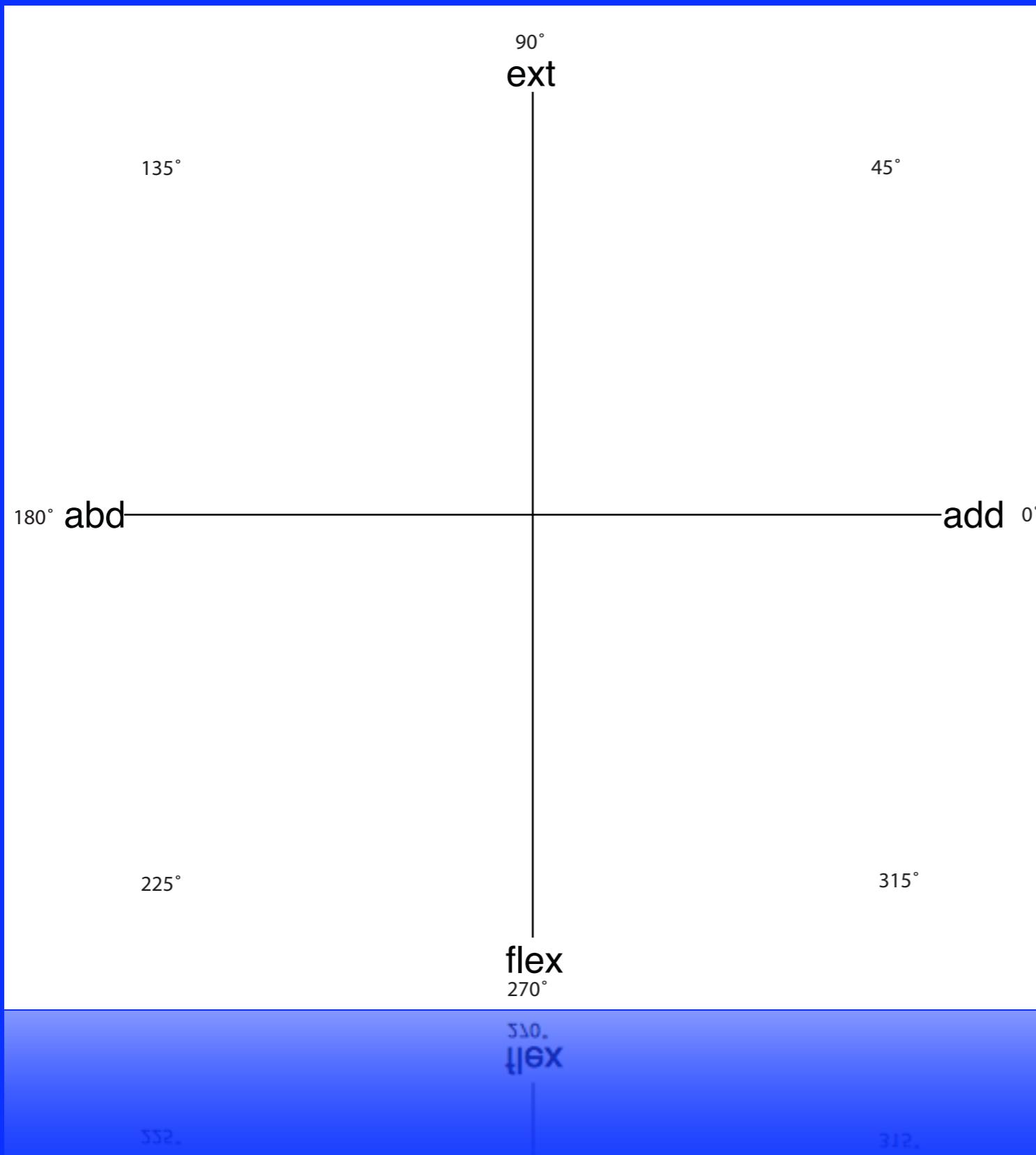


Force covariance mapping: entire dataset

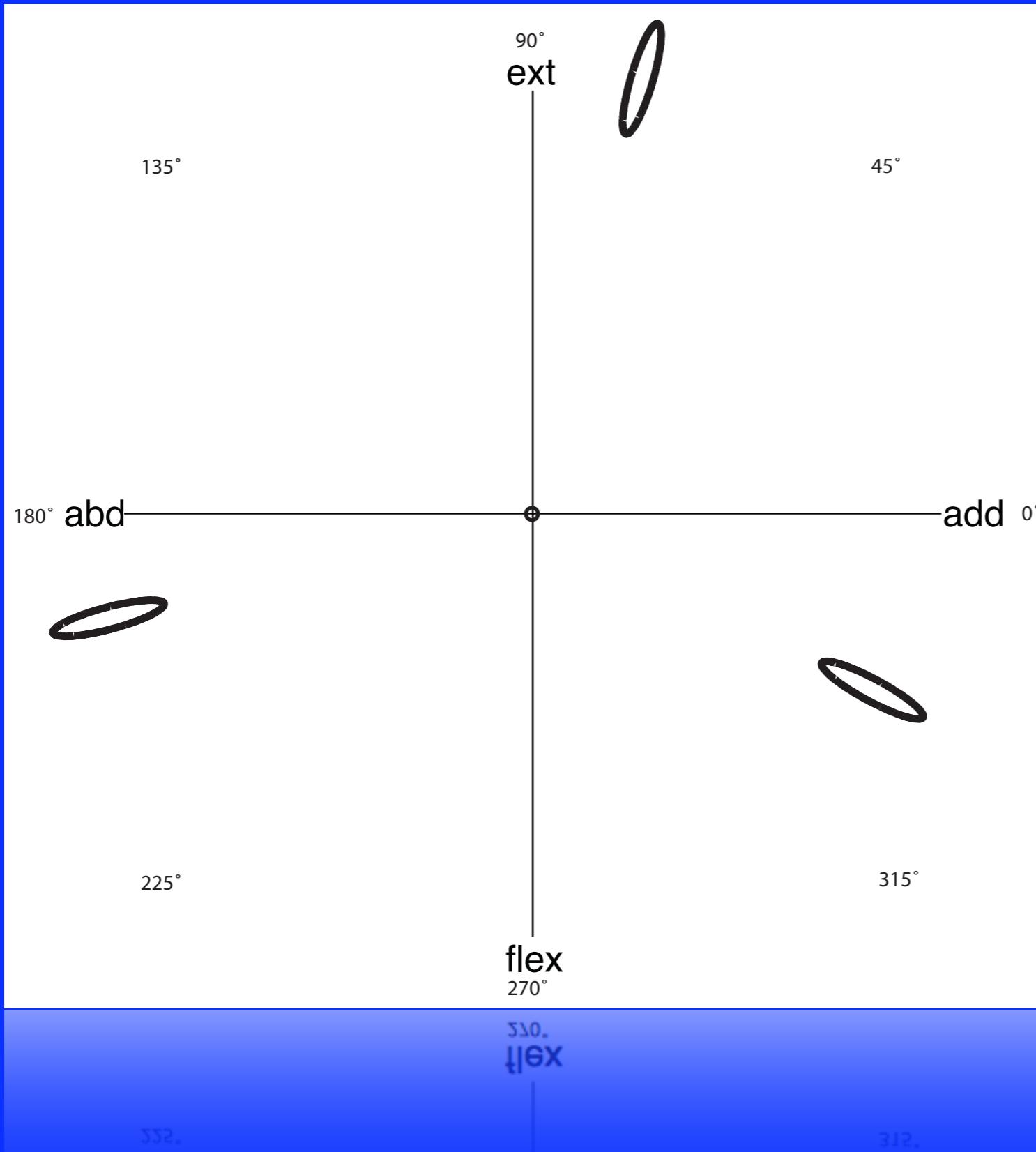


Force covariance mapping: statistical analysis

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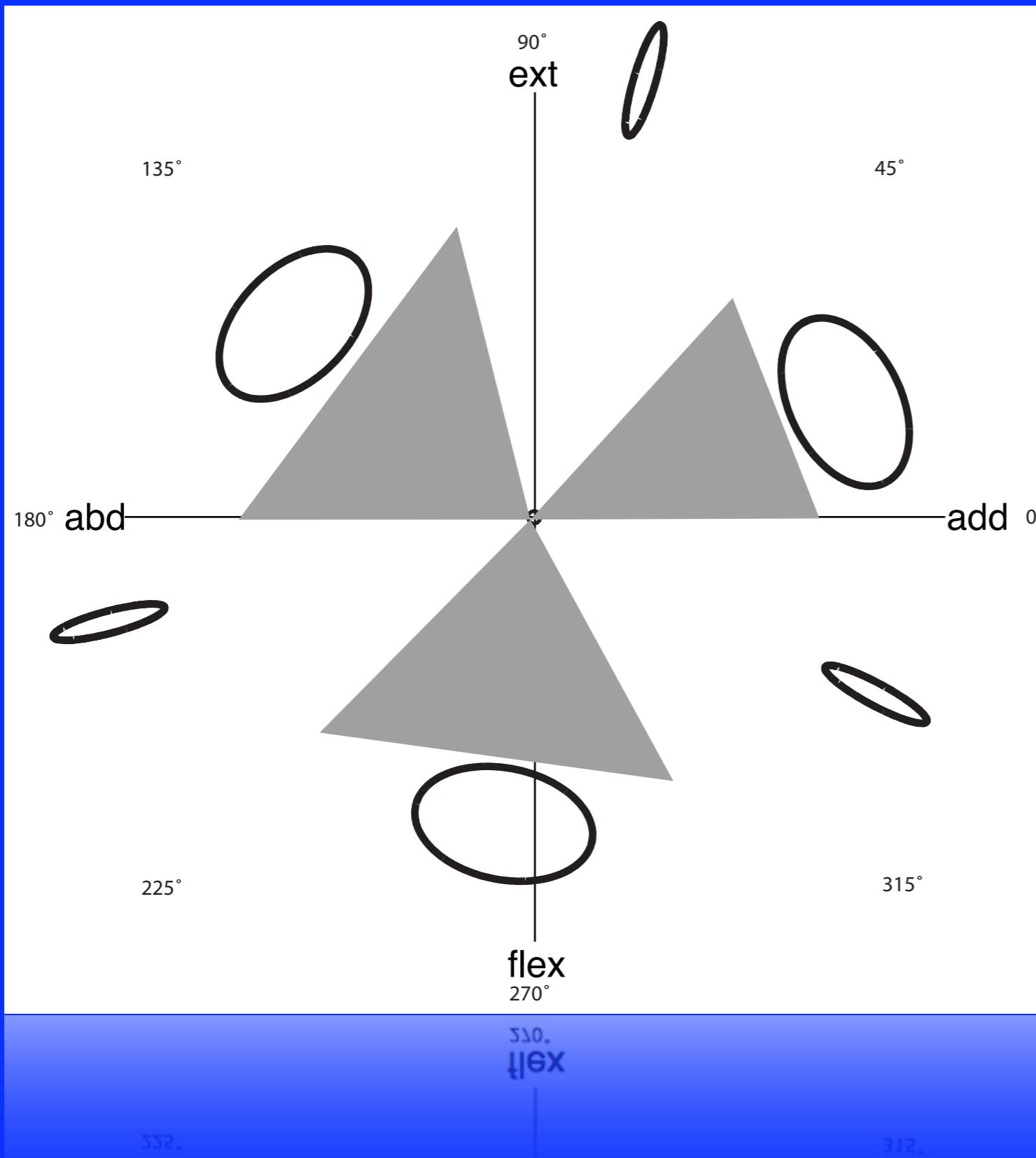


Force covariance mapping: statistical analysis



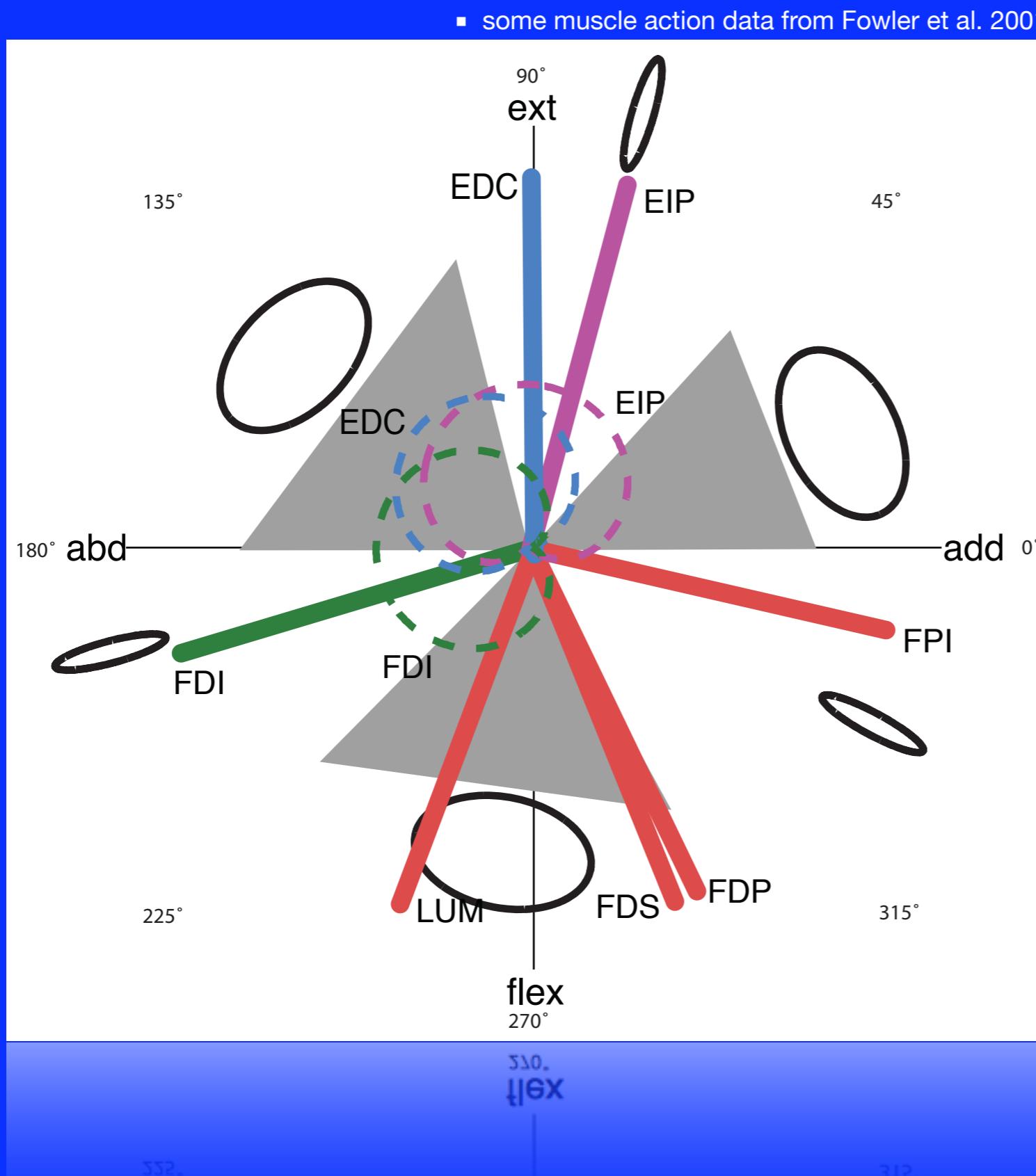
- 3 task directions had max task-directed ellipses

Force covariance mapping: statistical analysis



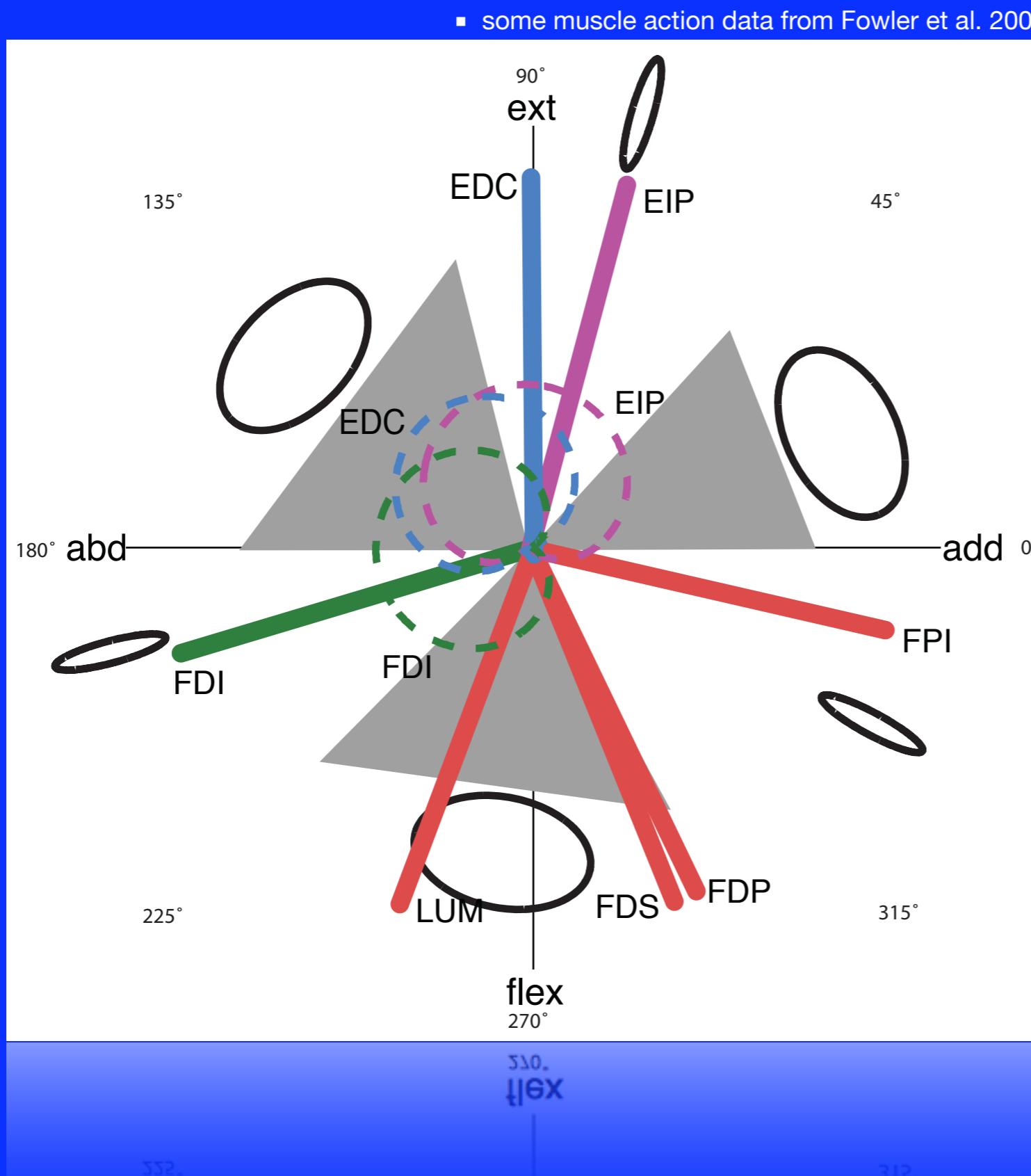
- 3 task directions had max task-directed ellipses
- Three ranges had sig. less task-directed ellipses

Force covariance mapping: statistical analysis



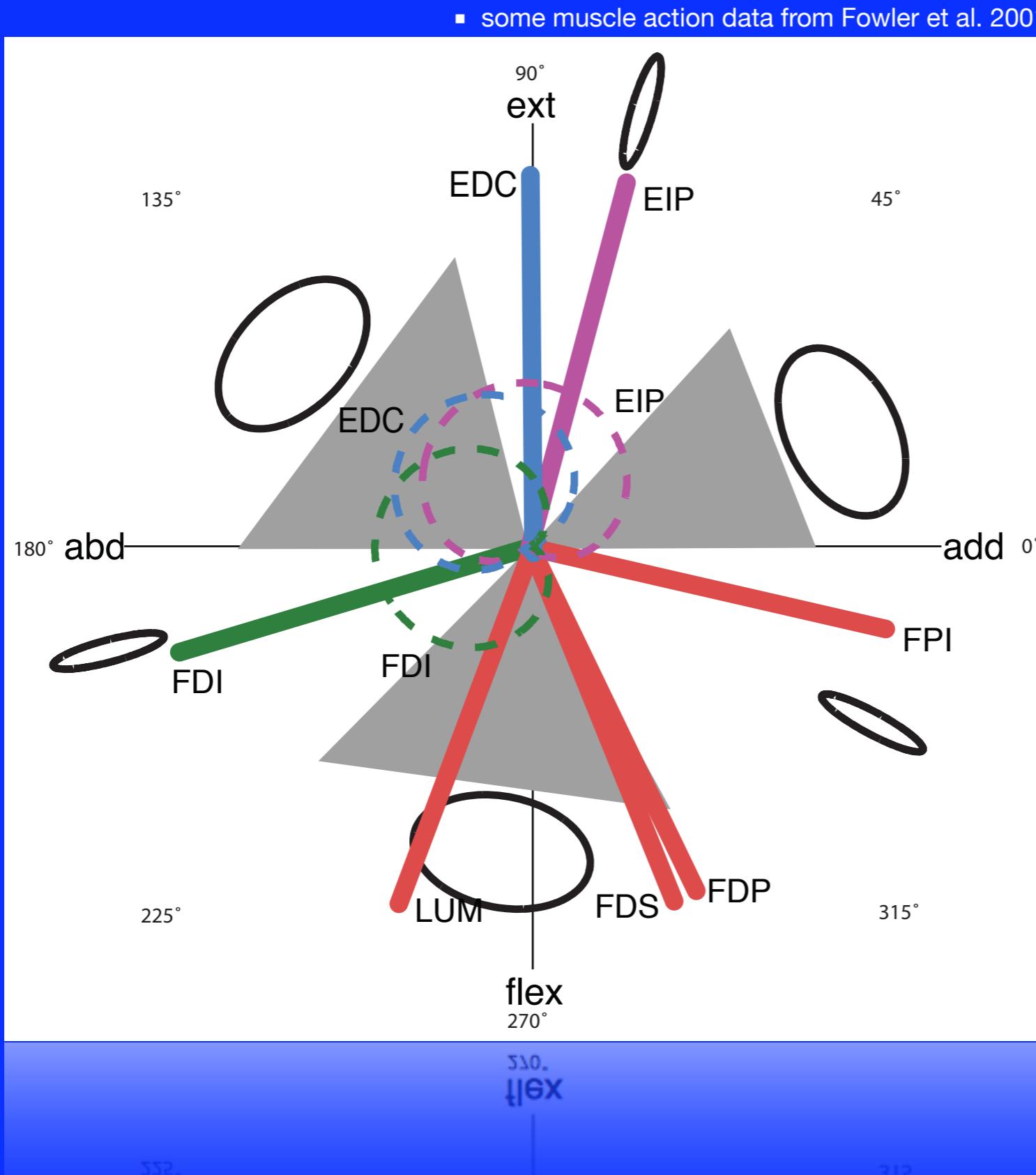
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Force covariance mapping: statistical analysis



- 3 task directions had max task-directed ellipses
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- Max task-directed ellipses were near directions of muscle action

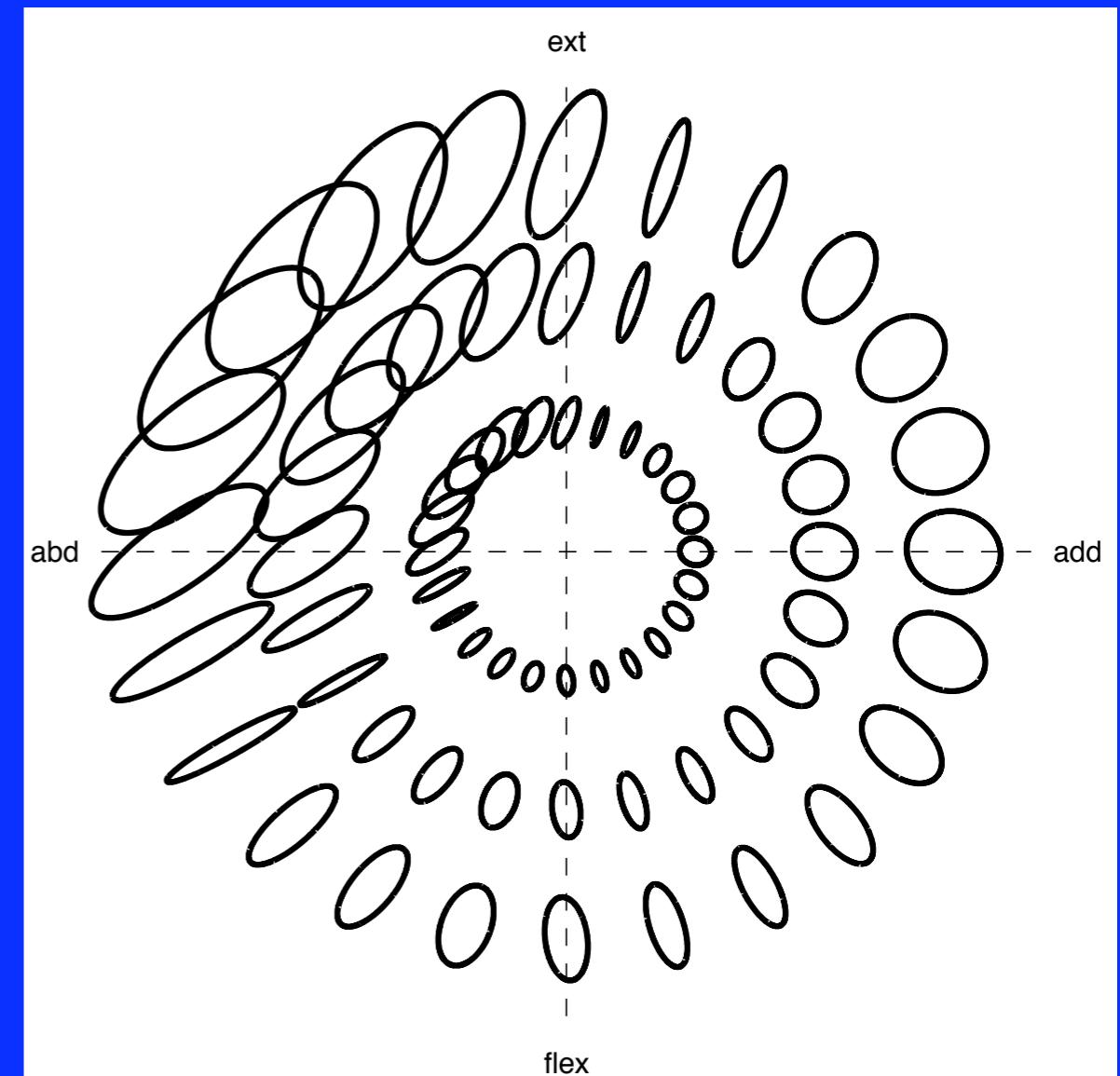
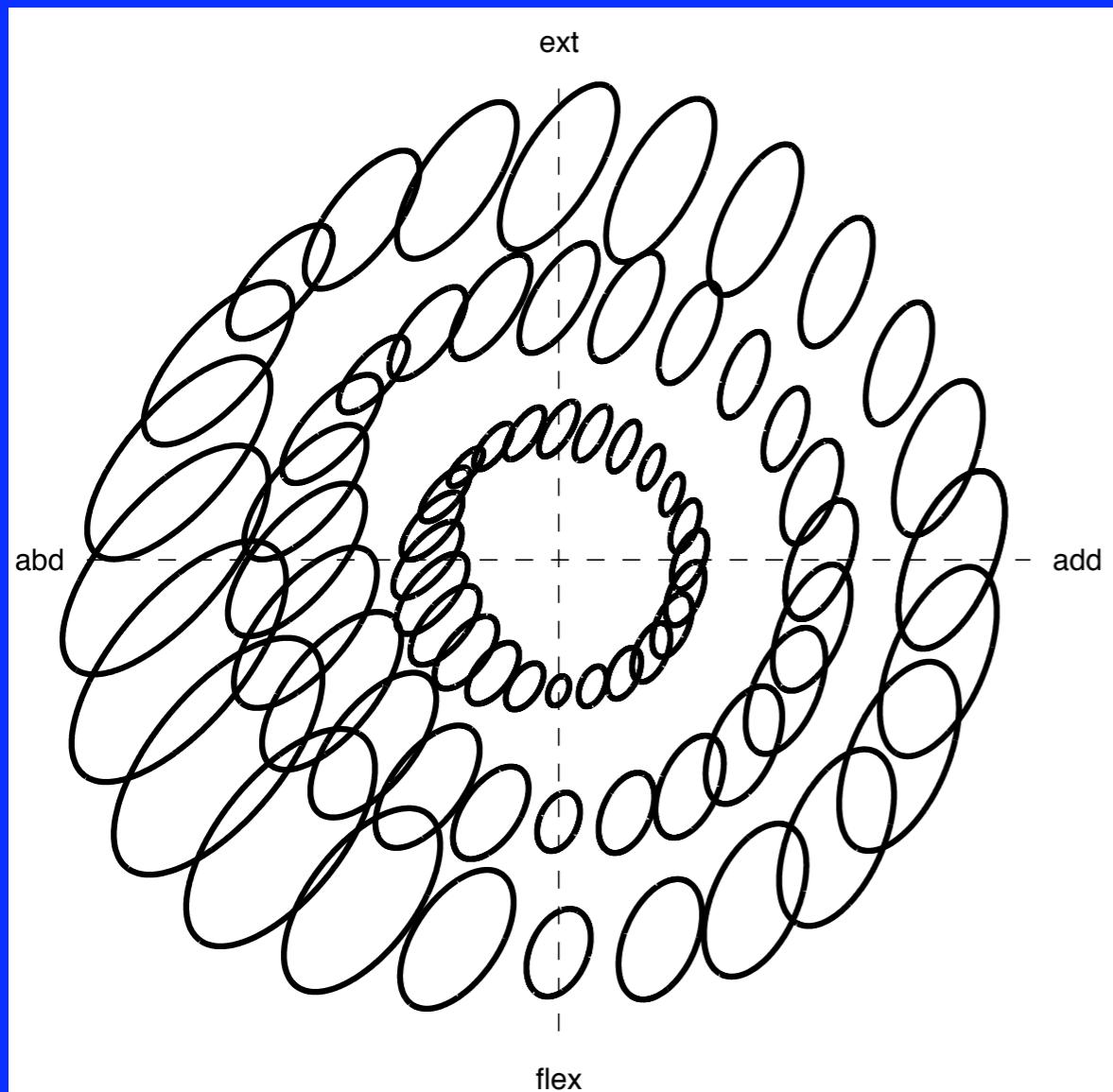
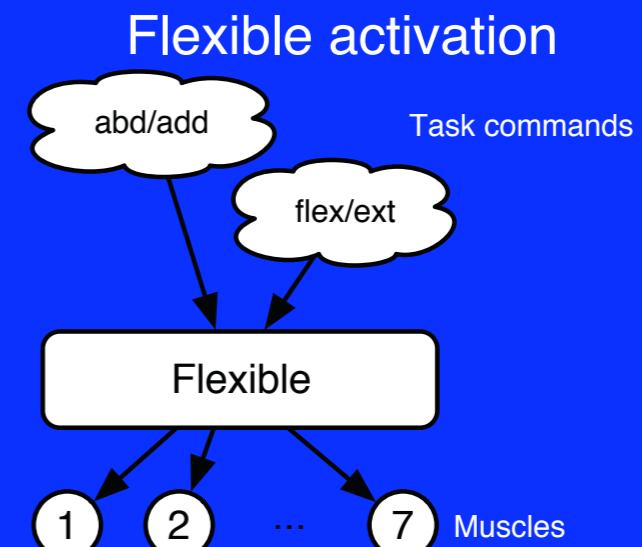
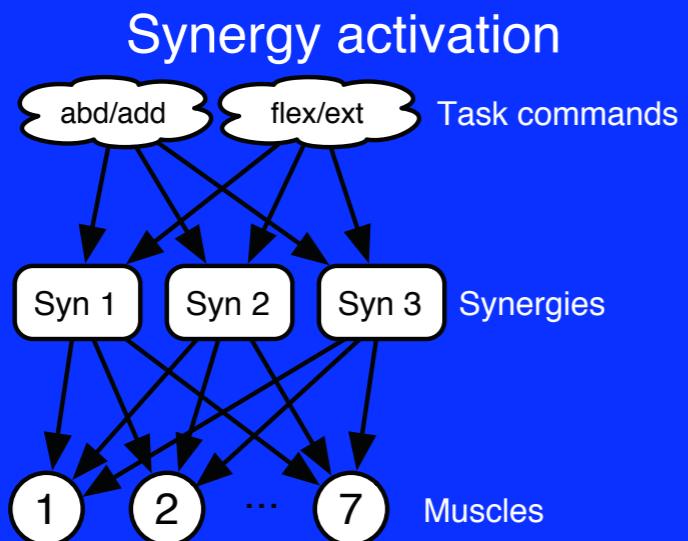
Force covariance mapping: statistical analysis



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- All three ranges of non-task-directed ellipses had muscle cooperation
- Max task-directed ellipses were near directions of muscle action
- Muscles with directed ellipses are not in strong synergies

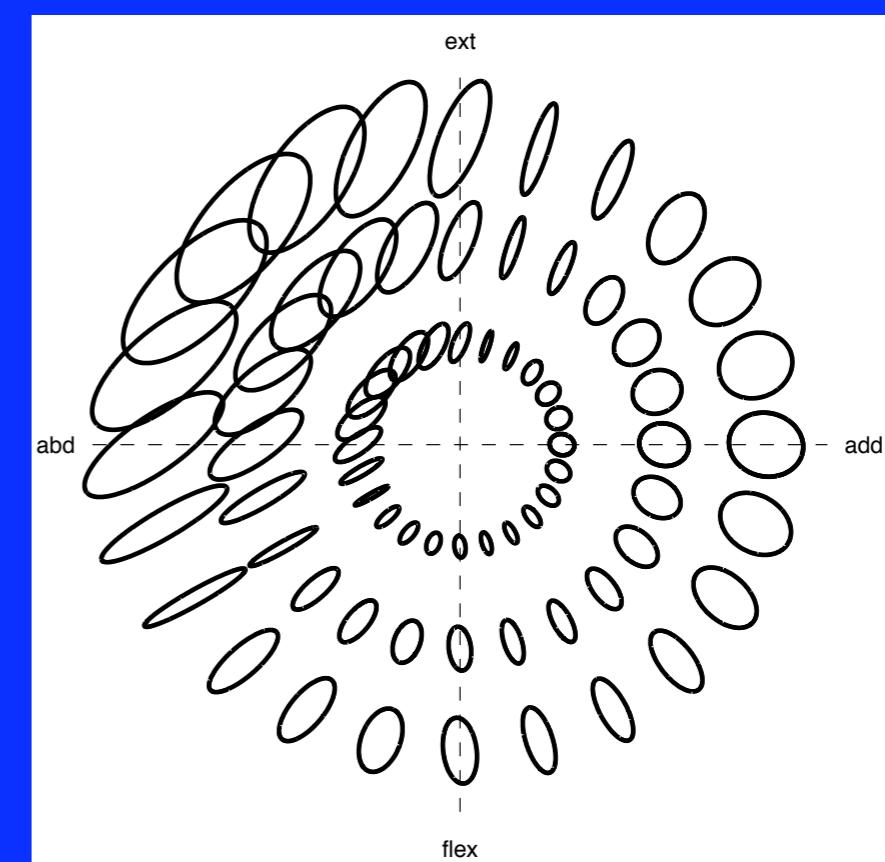
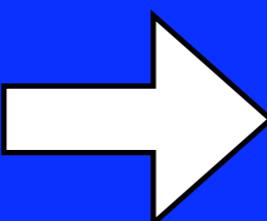
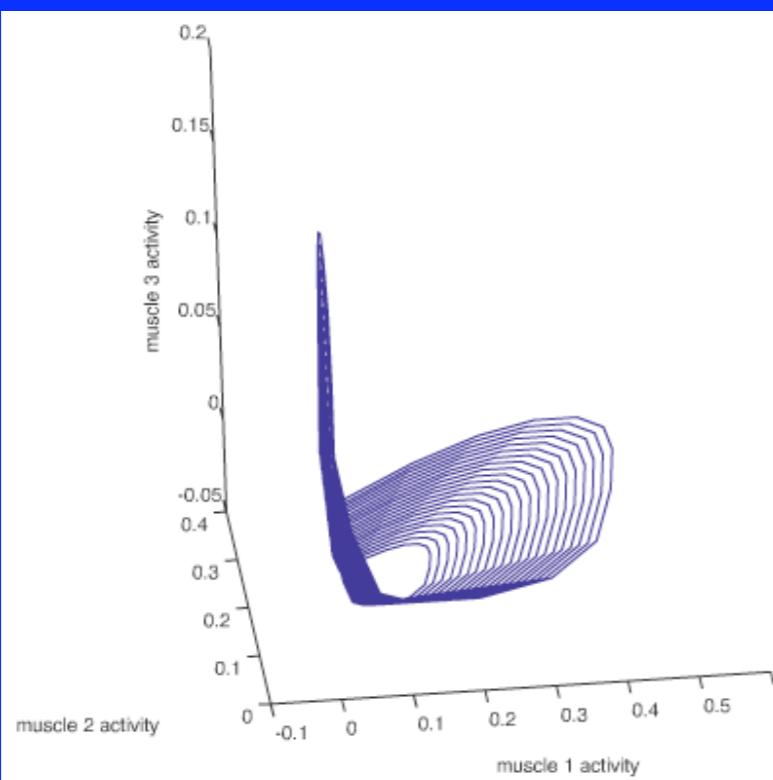
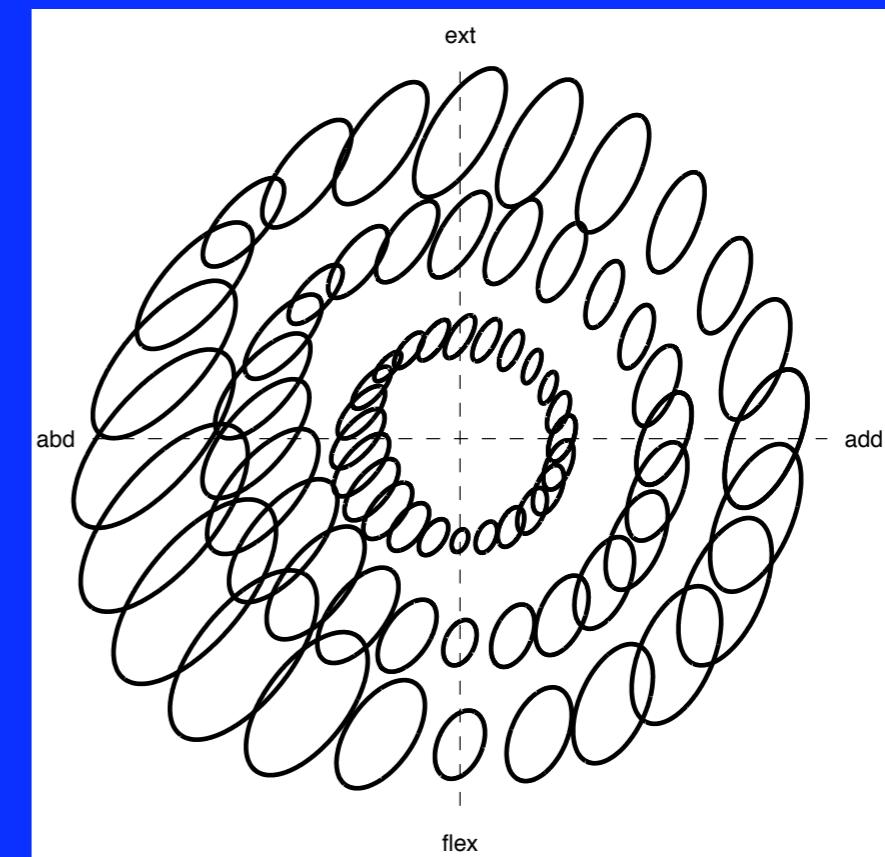
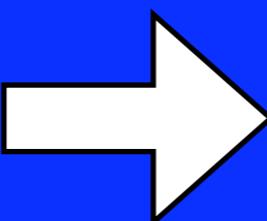
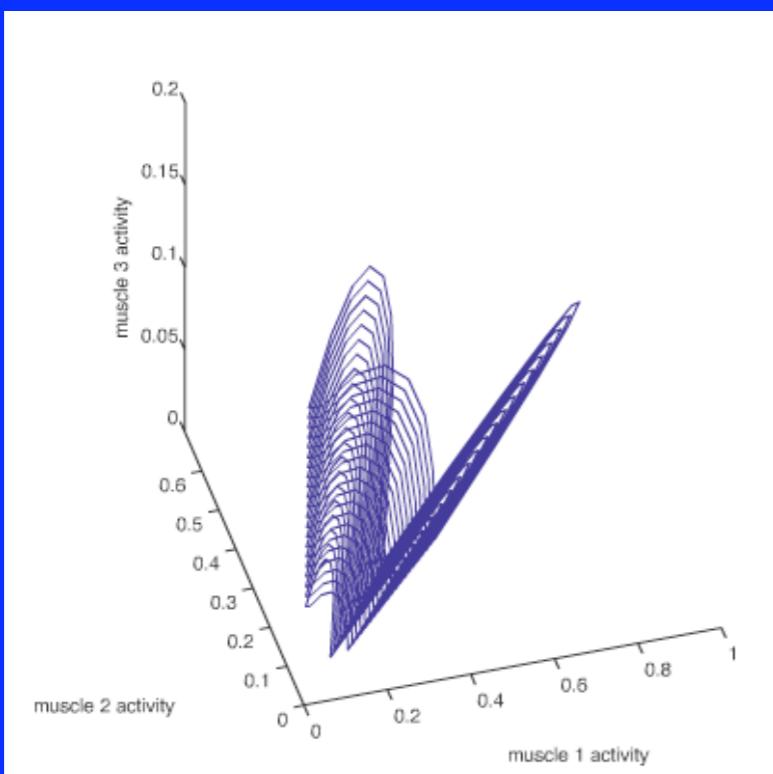
Two strategies - *different* force covariance map

Two strategies - different force covariance map



Why is the force covariance map different?

Why is the force covariance map different?



Summary

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- Task dimension may determine output dimension

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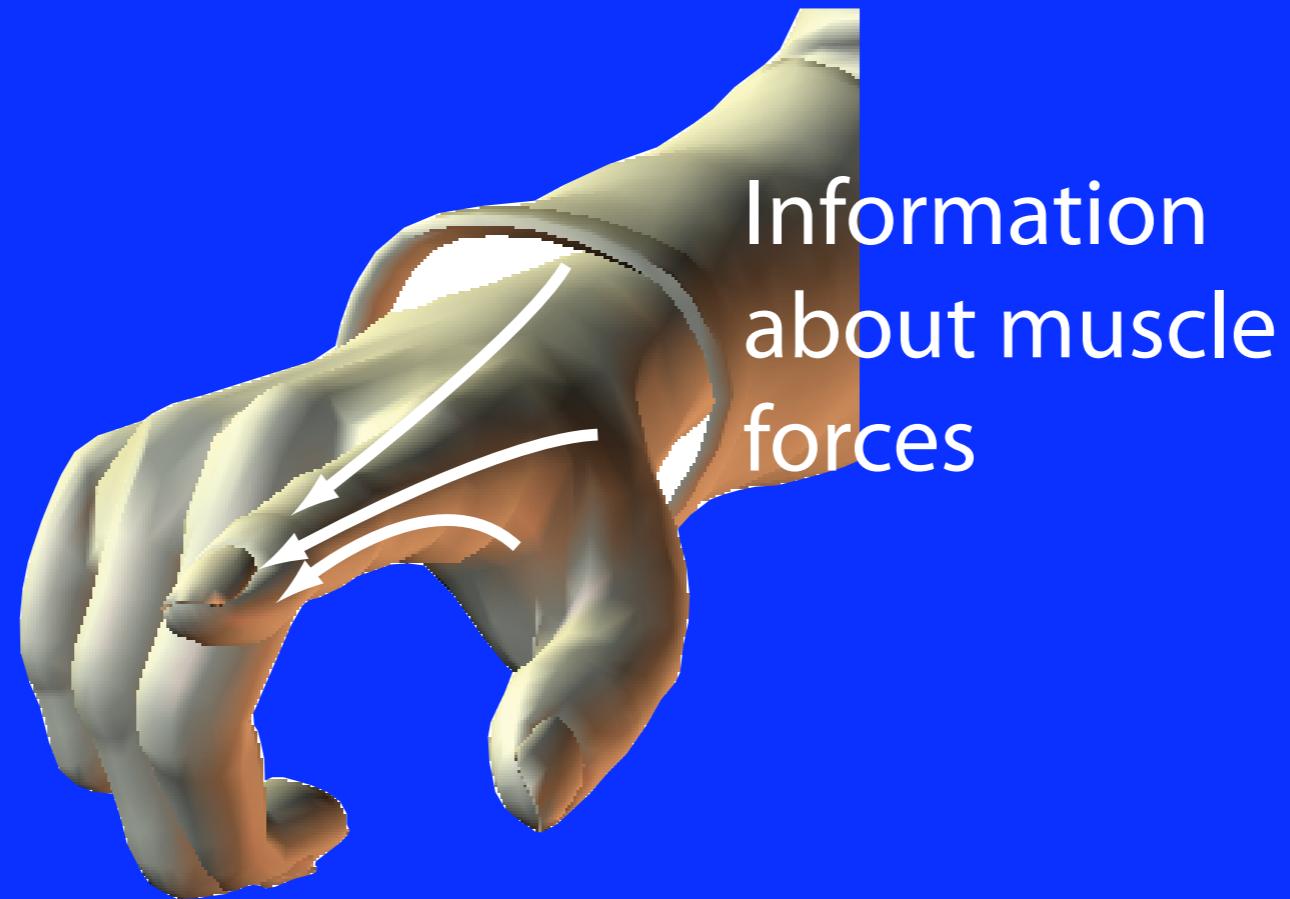
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- Non-synergistic behavior for index finger muscles

Acknowledgments

Dissertation Committee:

Professor Anthony Bloch, Co-chair
Associate Professor Arthur Kuo, Co-chair
Professor Edward Steunkel, Cognate
Assistant Professor Victoria Booth
Professor William Rymer, Northwestern University

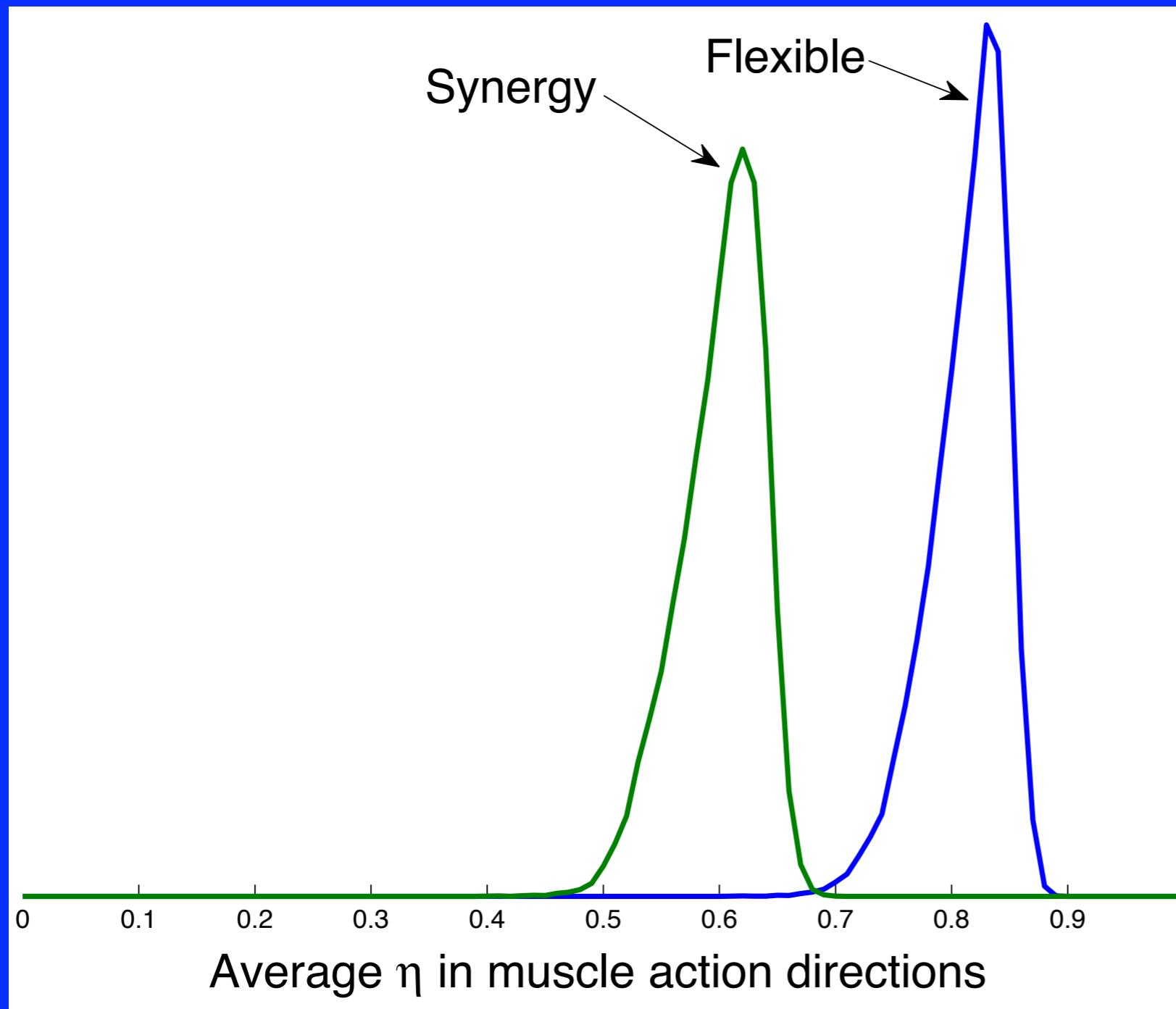
Sensory Motor Performance Program:

Nina Suresh
Carol Mottram
Matthieu Chardon
Stan Chikando
Ben Sinder

NIH NRSA training grant to JJK and WZR

Two strategies - parameter sensitivity

Two strategies - parameter sensitivity



Probability distribution over:

1. Synergy coupling weights
2. Signal-dependent noise constants
4. Correlation among muscle input signals