Joint-Based Velocity Feedback to Virtual Limb Dynamic Perturbations

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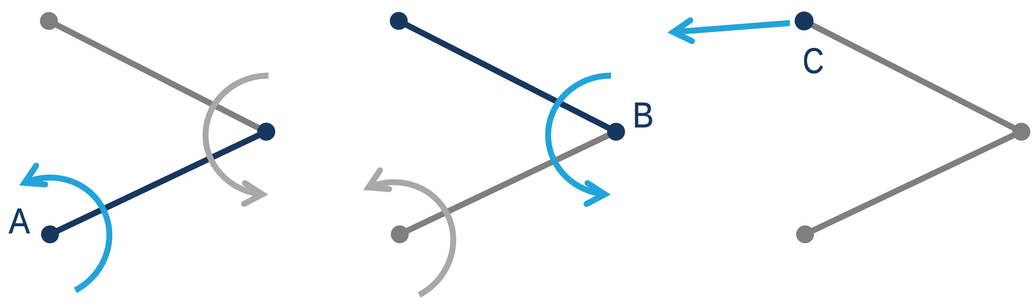
Introduction

- Upper-limb amputation reduces sensory feedback, contributing to difficulties performing activities of daily living [1]
- Few attempts to provide complementary sensory feedback have been successful in parallel with vision [2]
- There are three criteria for augmented feedback to be most useful
  - Provide information (i.e. velocity) not available to other senses, notably vision (i.e. position) [3]
  - Feedback should have low uncertainty compared to control of the task [4]
  - Provide information in the most uncertain reference frame (i.e. joint-based, rather than egocentric, reference frame) [5]
- These criteria suggest a joint-based velocity feedback paradigm will improve prosthetic arm control, even for those with unaffected vision

Just Noticeable Difference Task

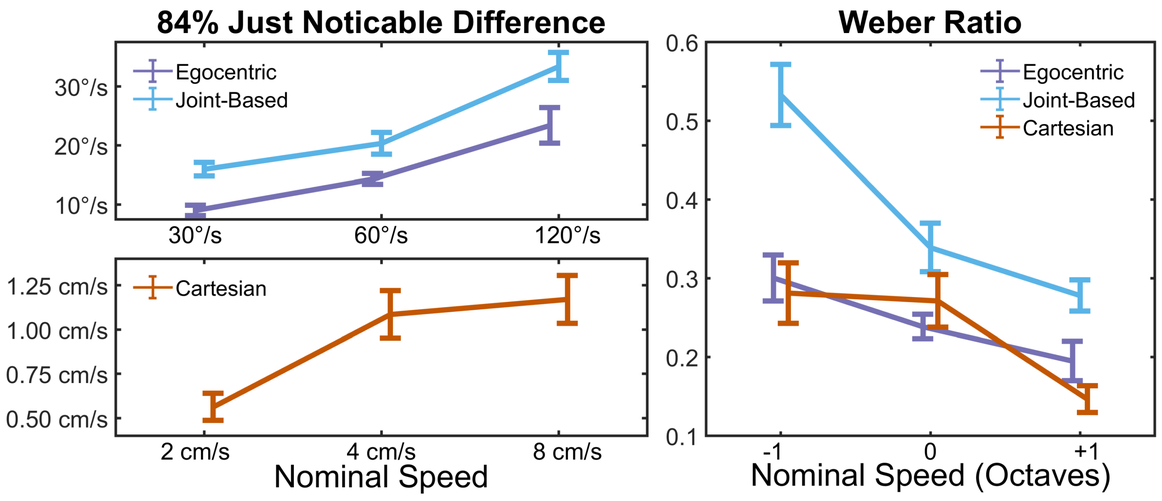
Methods: Two-Alternative Forced Choice

- Motivation: Determine visual discrimination of egocentric angular, joint-based angular, and cartesian speeds
- Two-alternative forced choice with adaptive staircase
  - Subjects shown two sequential movement examples and select example perceived as faster
  - 25 decision reversals, converge on 84% JND



Tested Object		Tested Speed	Slow	Medium	Fast
A	Proximal Link	Angular (Egocentric)	30°/s	60°/s	120°/s
B	Distal Link	Angular (Joint-Based)			
C	Endpoint	Cartesian	2 cm/s	4 cm/s	8 cm/s

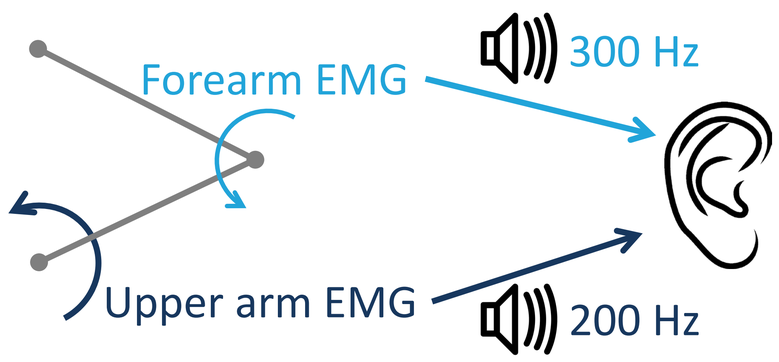
Results



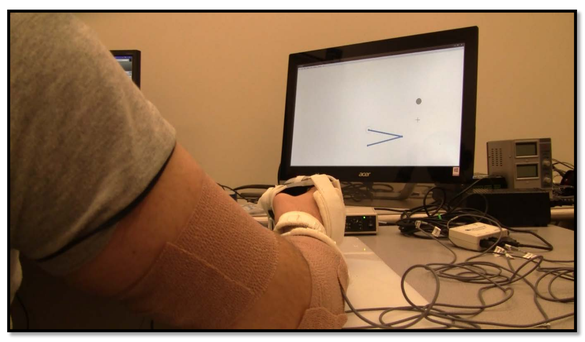
Center-Out Reaching Task

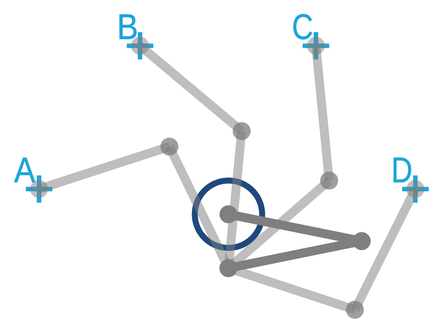
Methods: Two-Arm Linkage with Audio Feedback

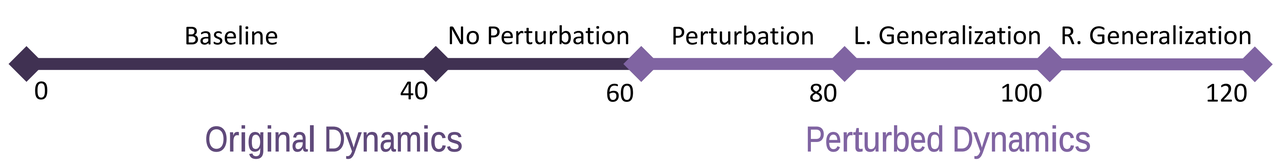
- Motivation: Complement egocentric and joint-based speed discrimination with proportional audio feedback
- 2-arm linkage with simulated dynamics
  - Joint torques proportional to enveloped EMG amplitude
  - Audio feedback volume proportional to joint speed



Methods: Center-Out Reaching Task

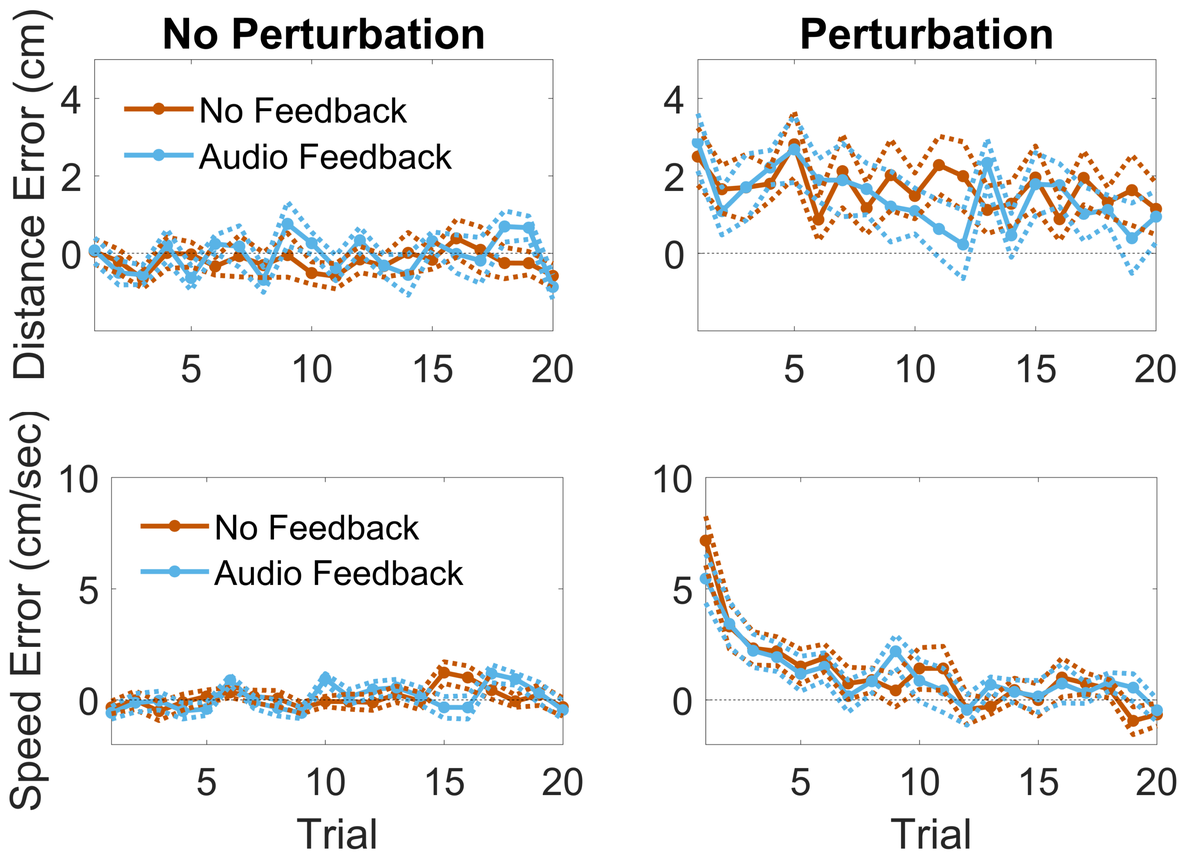






Testing Block	Baseline	No Perturbation	Perturbation	Left Generalization	Right Generalization
Trials	40	20	20	20	20
Target	Random	D	D	B	C

Results



Conclusion

- Discrimination of joint-based speed differences *significantly diminished* when moving slowly compared to egocentric speed
- During center-out reaching task, subjects subjectively reported *improved awareness of unintentional muscle contracture* and *increased embodiment of the virtual arm*
- Future work includes analysis of JND interaction between egocentric and joint-based linkage speeds, and simplified two-arm linkage control and audio feedback paradigm

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References

1. D. S. Childress, “Closed-loop control in prosthetic systems: Historical perspective,” *Ann. Biomed. Eng.*, vol. 8, no. 4–6, pp. 293–303, 1980.
2. C. Antfolk, M. D’Alonzo, B. Rosén, G. Lundborg, F. Sebelius, and C. Cipriani, “Sensory feedback in upper limb prosthetics.,” *Expert Rev. Med. Devices*, vol. 10, no. 1, pp. 45–54, 2013.
3. M. M. D. Sobuh, L. P. J. Kenney, A. J. Galpin, S. B. Thies, J. McLaughlin, J. Kulkarni, and P. Kyberd, “Visuomotor behaviours when using a myoelectric prosthesis,” *J. Neuroeng. Rehabil.*, vol. 11, no. 1, pp. 1–11, 2014.
4. M. O. Ernst and M. S. Banks, “Humans integrate visual and haptic information in a statistically optimal fashion.,” *Nature*, vol. 415, no. 6870, pp. 429–433, 2002.
5. M. Berniker and K. Kording, “Estimating the sources of motor errors for adaptation and generalization,” *Nat. Neurosci.*, vol. 11, no. 12, pp. 1454–1461, 2008.

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