Behavioral and EEG Features of Finger Proprioception and Passive Movement: Effect of Error Feedback on Proprioception

Andria J. Farrens[1], Monica Torrecilla[1,2], Luis Garcia Fernandez[1], Christopher A. Johnson[1], Eric T. Wolbrecht[3], David J. Reinkensmeyer[1], Disha Gupta[4,5]
[1] Biorobotics Laboratory, Mechanical and Aerospace Engineering, Univ. of Cal., Irvine; [2] ICFO - Institut de Ciències Fotòniques, Barcelona, Spain; [3] Mechanical Engineering, Univ. of Idaho, Moscow, ID;
[4]Natl. Ctr. for Adaptive Neurotechnologies, Stratton VA Med. Center, Albany, NY, ALBANY, NY; [5] Electrical and Computer Engin., State Univ. of New York, Albany, Albany, NY
farrensa@uci.edu

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Importance of Proprioception

- Proprioception is our sense of body position, movement, and force
- Impaired proprioception occurs in up to 80% of stroke survivors, and results in impaired motor control and reduced responsiveness to rehabilitation [1-3].
- We are interested in understanding how to enhance proprioception.

Research Questions

Here, we used the proprioceptive "Crisscross" task on Finger Individuating Grasp Exercise Robot (FINGER) [3-4], to determine:

1. Does providing error feedback improve proprioceptive performance?
2. Is there an EEG response to error feedback provided after a Crisscross trial ("feedback response")?
3. Is there an anticipatory EEG response to the impending crossing of the fingers during Crisscross ("CNV response")?

Experimental Design & Methods

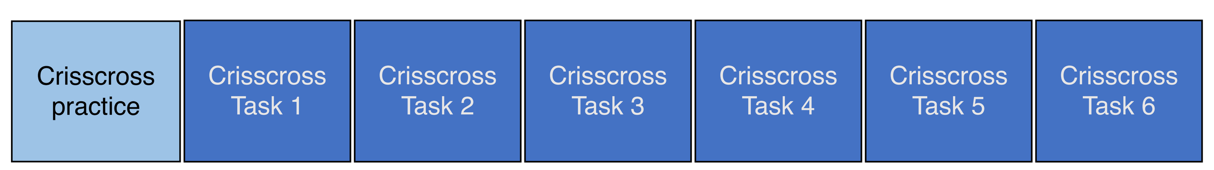


Figure 1. Experimental protocol

Participants:

- 20 healthy adults, aged 22-34 years, right hand dominant

Protocol:

- **Crisscross:** Participants push a button at perceived finger joint alignment as a robot passively crosses two joints, with vision of the hand occluded [2,4].
- Following a brief training, participants performed 6 consecutive runs (120 crossings total)
- Text feedback was displayed immediately after button press
  - **No Feedback Group (nFB)** received "button press" display
  - **Feedback Group (FB)** received their percent error magnitude

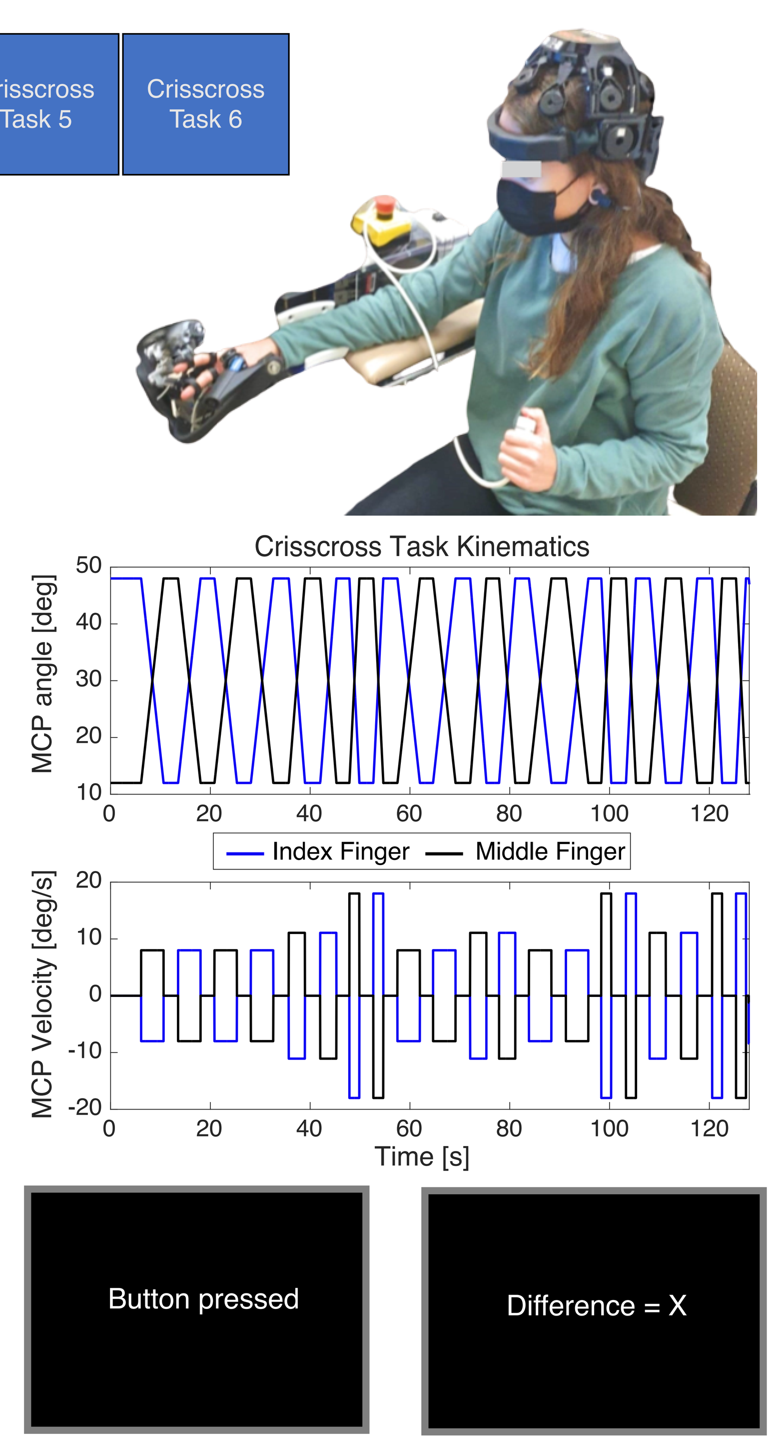
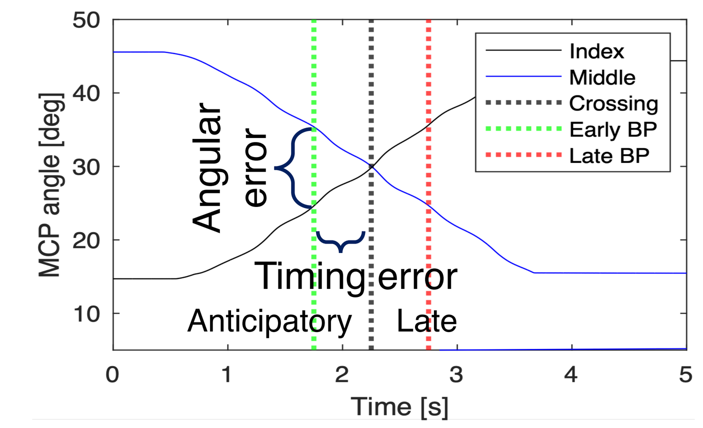


Figure 2. Top: FINGER robot used for assessment of the index and middle fingers. Middle: Finger kinematics during each crisscross task. Bottom: Screen feedback

Experimental Analysis

Behavioral Data

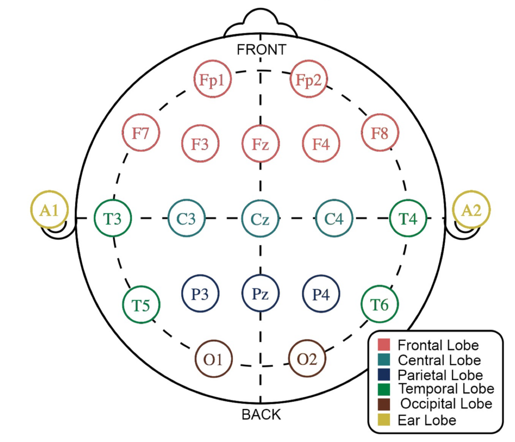
- Absolute errors
  - Magnitude of angular error at button press
- Timing errors
  - Crossing time-button press time



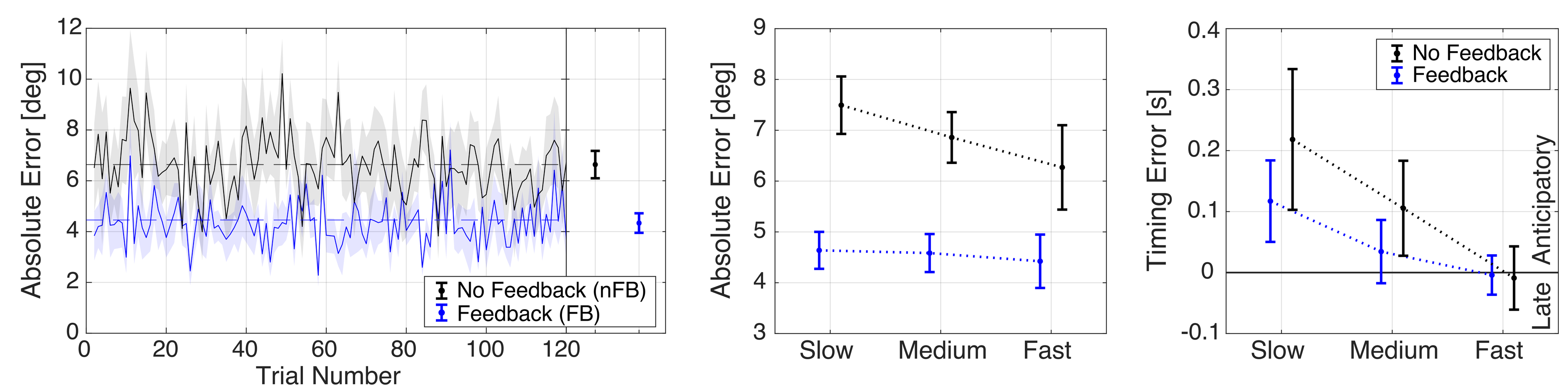
EEG Data

1. Bandpass filtered [0.5-35Hz], ICA denoised.
2. Epoched with respect to button presses or movement onset. Baseline corrected with respect to movement onset (-200 to 0 ms). Noisy trials removed (+/- 100µV, <5% trials).
3. Event Related Potentials (ERPs) calculated as the mean across denoised trials.

Electrode Configuration

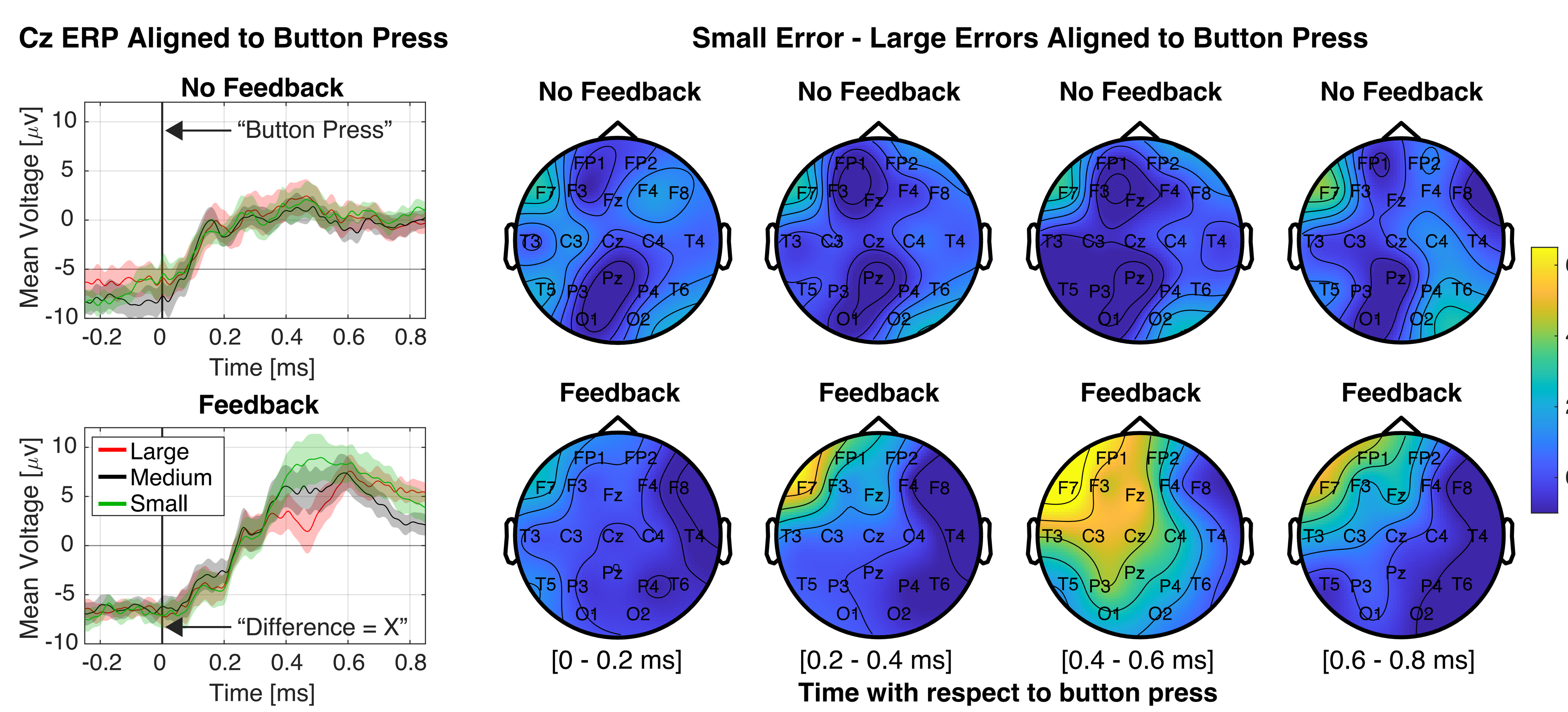


1. Behavioral Results



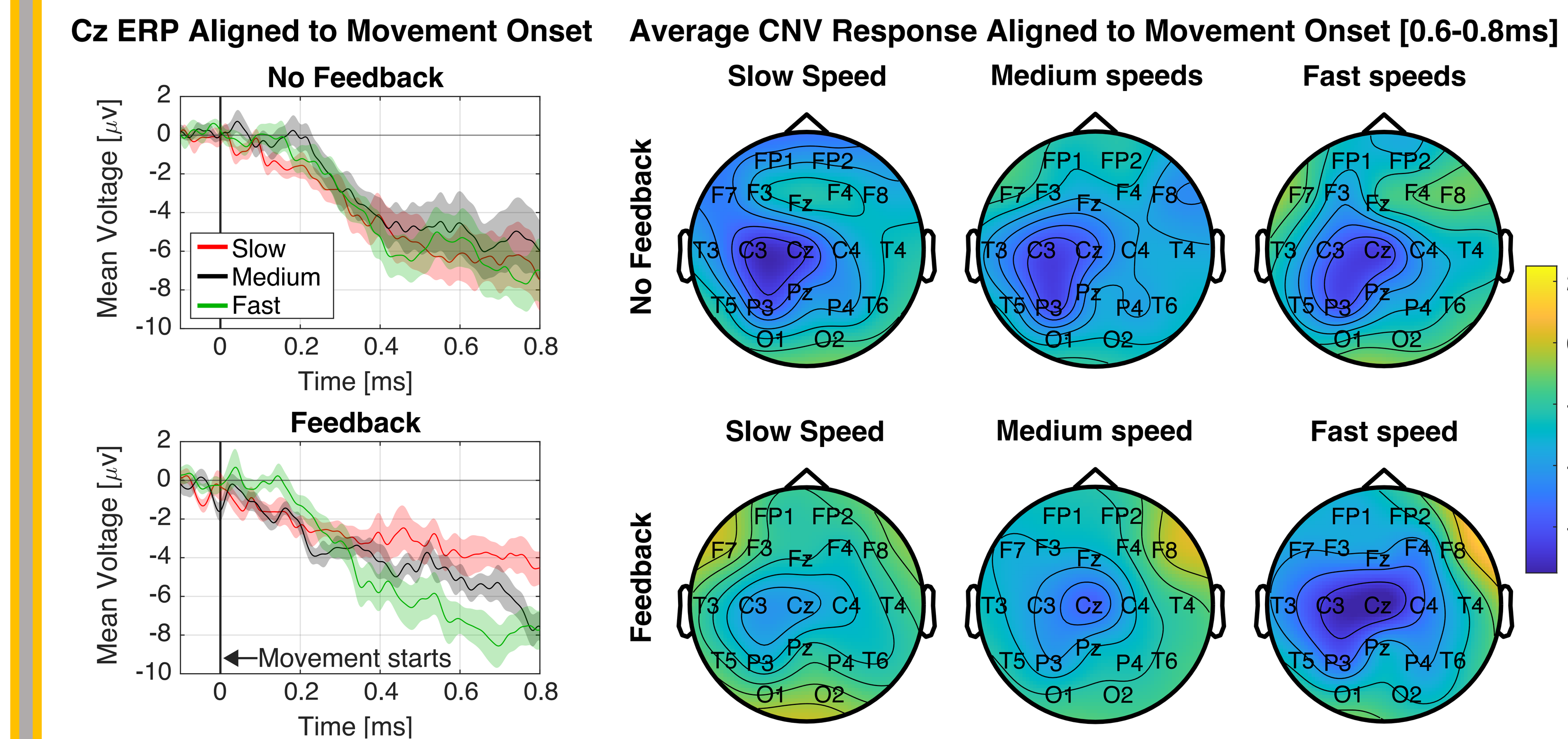
Proprioceptive errors were smaller in the FB group compared to the nFB group (t-test, $p < 0.01$). In the nFB group, errors in slow trials were worse than fast trials (t-test, $p<0.05$); there was no difference between speeds in the FB group.

2. Feedback Response



Feedback response at Cz: 400-600 ms post button press, the FB group had a lateralized ERP response in frontoparietal regions contralateral to the proprioception hand, which increased with error magnitude (kw-test, $p < 0.01$), that was absent in the nFB group

3. Contingent Negative Variation



Contingent Negative Variation (CNV) at Cz: Observed to peak at perceived finger crossing, time locked to movement onset. A mixed model (factors: feedback, speed) performed on Cz magnitude returned an interaction between feedback and speed ($p < 0.03$). In the FB group, CNV magnitude increased with finger speed but not in the nFB group. The CNV difference in slow conditions may explain improved performance on slow trials in the FB group.

Conclusions

- The sensory system can incorporate feedback to improve proprioception during Crisscross
- There is an EEG brain marker of the feedback process in frontoparietal regions contralateral to the proprioception hand
- There is an EEG brain marker of anticipatory processing of proprioceptive information during Crisscross (CNV response). To our knowledge, a proprioceptive CNV response has not been shown before. Critically, feedback after performance modulates anticipatory processing in the CNV that leads to improved acuity
- **Future work:** These findings provide possible targets for evaluating and training proprioception following stroke.

References

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