Electroencephalogram analysis of finger proprioception in healthy subjects

Mónica Torrecilla Vall-llossera[1], Dr. Andria Farrens[2], Dr. Disha Gupta[3], Dr. David Reinkensmeyer[2]

[1]Biorobotics Laboratory, University of California, Irvine (currently at ICFO - Institut de Ciències Fotòniques, Barcelona, Spain), [2]Biorobotics Laboratory, University of California, Irvine. [3]National Center for Adaptive Neurotechnologies, Stratton VA Medical Center, New York.

Background

Proprioception, our sensation of body position, movement and force, is key to motor control and motor learning. When this sense is affected, it can make movement and coordination difficult, as occurs in conditions like cerebral palsy and stroke.

To evaluate proprioception, we use the **Criss Cross** (CC) assessment, a novel passive robotic assessment that allows for fast and precise measurements of proprioception without requiring any motor ability.

The primary **objective** of our study is to gain insights into the cortical processing during the execution of the CC task in healthy participants, facilitated by the FINGER Robot. Through examination of brain signals recorded throughout the task, our aim is to identify specific features within the Electroencephalogram (EEG) signal that may provide clues to the neural mechanisms underlying proprioception during the CC task.

Methodology

Criss Cross task:

Nine healthy adults (22-34 years, 2F/7M), participated in the CC task with their **right hand** placed in the FINGER robot. FINGER passively crossed the index and middle fingers in **alternating flexion/extension** (0-36deg) at **random speeds** (16, 22, 36 deg/s). **The vision of the hand was obscured** by a black screen placed in front of it. Non-invasive scalp EEG was acquired (DSI-24, Wearable Sensing, CA) at 300 Hz during the task.

Data was collected for the following 2 conditions:

- Criss Cross Pressing Button (CC-PB): Participant pressed the button when they perceived their index and middle fingers overlap.
- Criss Cross Non-Pressing Button (CC-NPB): Experimenter pressed the button when they observed the participant's index and middle fingers overlap.

Twelve runs of 20 trials/run were collected per participant (6 runs CC-NPB, followed by 6 runs CC-PB), i.e. 240 trials per participant. Inter-trial interval was 2 - 3.5s.

Feedback (based on proprioception error), was shown after each trial.

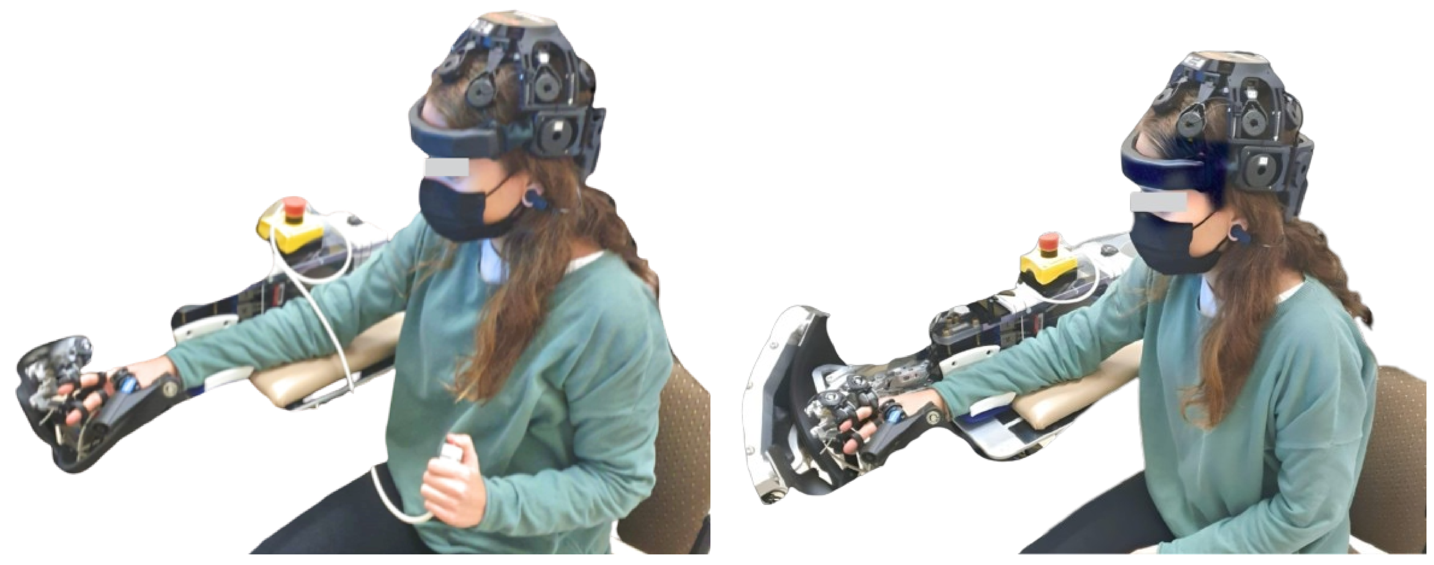

Figure 1. Left: participant performing the CC-PB task, with the right hand on the FINGER and the button in the left hand. Right: participant performing the CC-NPB task.

Data processing:

1. **Preprocessing**: Filtering (bandpass filter [0.5-45Hz]). Independent Component Analysis (ICA) for eye artifact removal.
2. **Synchronization**: Robot and EEG data were synchronized using button presses as a common reference point.
3. **Segmentation**: EEG data were segmented into epochs aligned with button presses or movement onset.
4. **ERP Extraction**: Outlier handling, Common Average Reference (CAR), trial averaging, and smoothing.

Event-Related Potentials (ERPs): Brain's electrical activity time-locked to specific events or stimuli, in our case movement onset and button press. For capturing relevant brain activity, we focused on electrodes:

- **Cz**: to analyze the Contingent Negative Variation (CNV), a negativity that emerges after an imperative cue (movement onset), that anticipates an impending stimuli or action (i.e. finger crossing).
- **P3**: to investigate brain response to proprioceptive sensory processing.
  - **Effect of Speed**: Fast movements (36deg/s) vs slow (16deg/s) have also been explored in modulating activity.

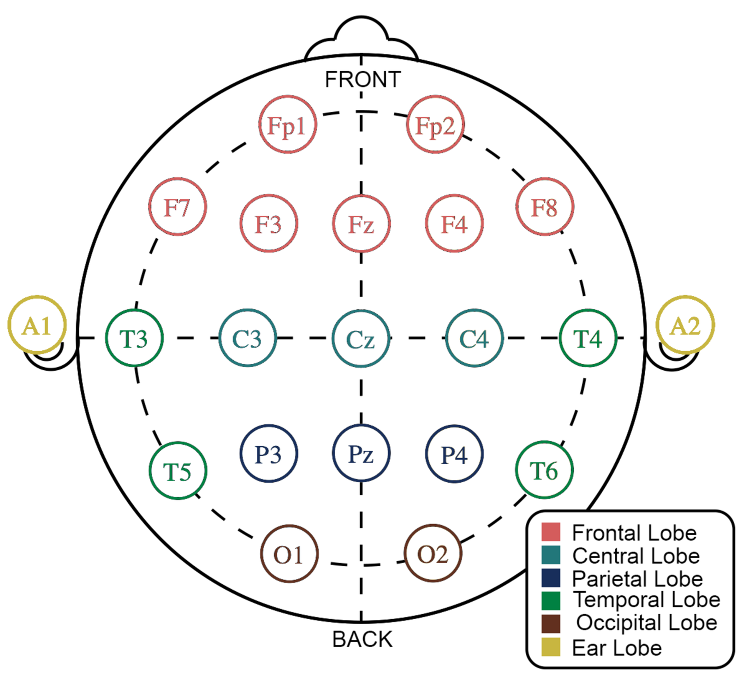

Figure 2. Representation of the EEG electrode placement following the 10-20 system.

Results: Proprioceptive decision making

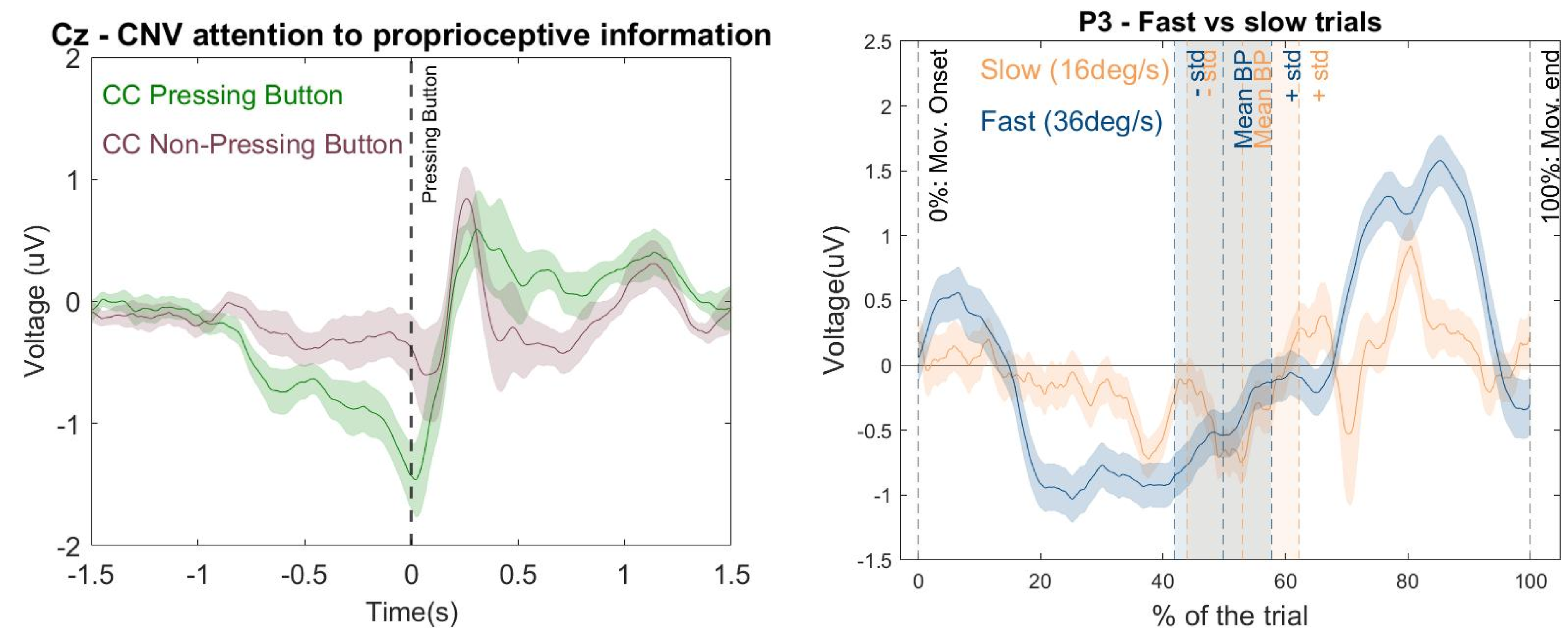

Figure 3. Left: ERP comparison for CC-PB and CC-NPB groups (channel Cz). CNV observed in the CC-PB group associated with the subjects having to rely on proprioception to press the button. Right: ERP comparison of CC-PB fast and slow trials. A faster movement generates a greater proprioceptive response.

Results: Feedback response

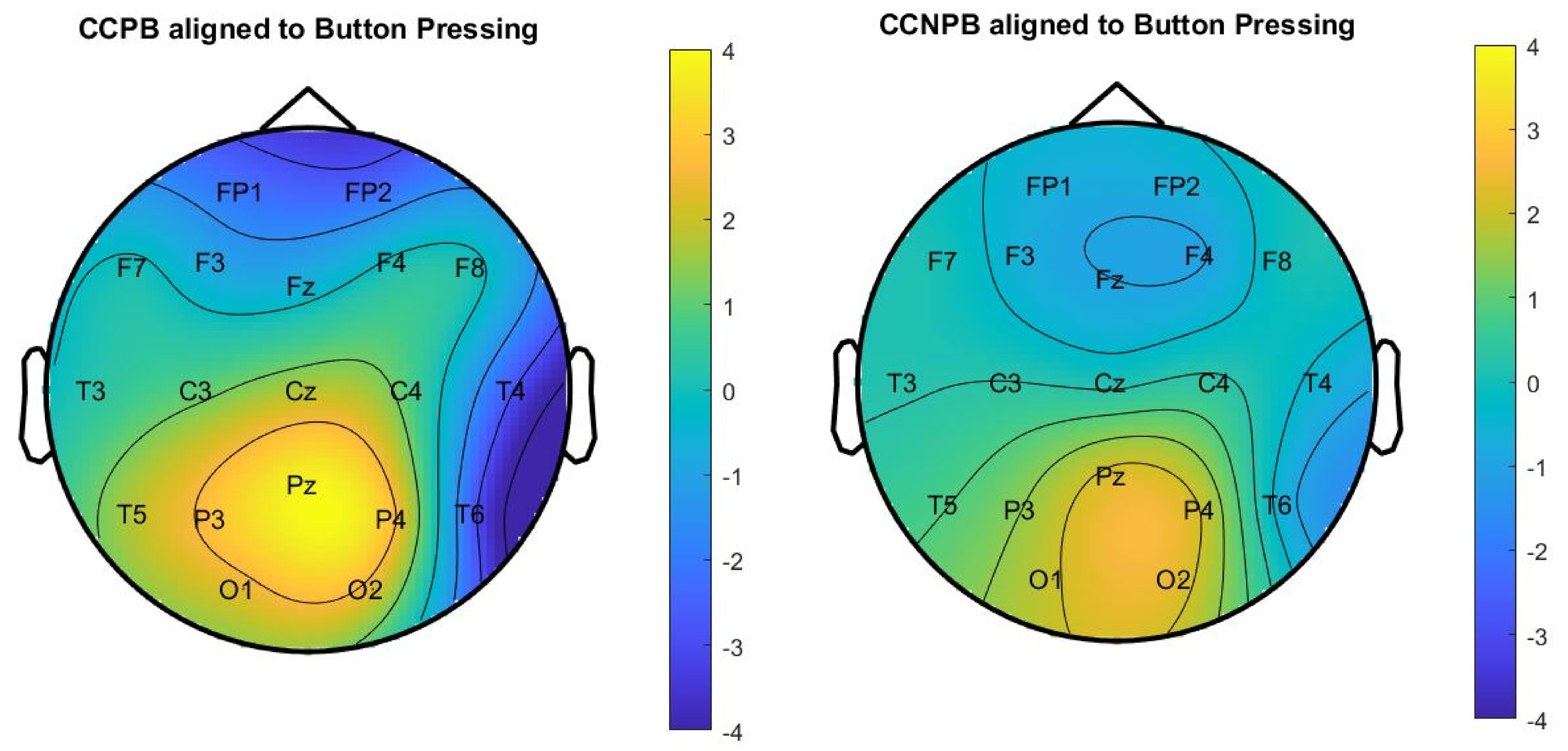

Figure 4. Topography representing the mean value (μV) in the range [0.4s – 0.7s] of the ERP aligned to the button pressing. Left: CC-PB group. Right: CC-NPB group. Increased activity in proprioceptive regions during the CC-PB task compared to the CC-NPB task, where decisions rely on proprioceptive information.

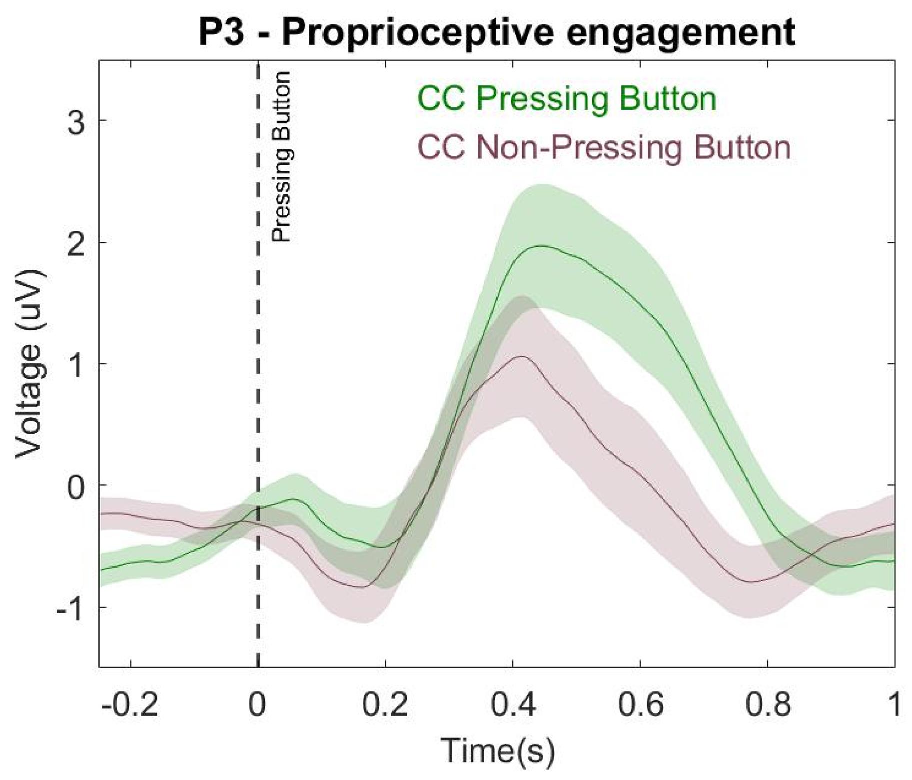

Figure 5. ERP comparison for CC-PB and CC-NPB groups (channel P3). Trials aligned to button pressing. Shows more proprioceptive engagement in the CC-PB task.

Conclusions

Novel EEG markers of proprioceptive processing:

1. **CNV response**: begins at passive movement onset. Negative slope tracks movement progression, but only if participant's are actively involved.
2. **ERP response**: increases with increasing finger speed.
3. **Feedback response**: occurs following button press, increases if participants are actively performing the task.

Future work will assess how these responses vary with Criss Cross performance errors.

[1] Patrick Ofner, Andreas Schwarz, Joana Pereira, and Gernot R. Müller-Putz. Upper limb movements can be decoded from the time-domain of low-frequency eeg. *PLOS ONE*, 12(8), 2017.

[2] Jia Han and et al. Assessing proprioception: A critical review of methods. *Journal of Sport and Health Science*, 5(1):80–90, 2016.

[3] H. Taheri, J. B. Rowe, D. Gardner, V. Chan, D. J. Reinkensmeyer, and E. T. Wolbrecht. Robot-assisted guitar hero for finger rehabilitation after stroke. *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2012.

[4] Leoni Winter, Qiyin Huang, Jacquelyn V. Sertic, and Jürgen Konczak. The effectiveness of proprioceptive training for improving motor performance and motor dysfunction: A systematic review. *Frontiers in Rehabilitation Sciences*, 3, 2022.

[5] Riemann BL; Lephart SM;. The sensorimotor system, part ii: The role of proprioception in motor control and functional joint stability. *Journal of athletic training*, 37(1):80-4, 2022.

[6] Pouya Ahmadian. *Development of Soft Computing Algorithms for the Analysis and Prediction of Motor Task from EEG data*. PhD thesis, 03 2014.

[7] I-Ling Yeh, Jessica Holst-Wolf, Naveen Elangovan, Anna Vera Cuppone, Kamakshi Lakshminarayan, Leonardo Cappello, Lorenzo Masia, and Jürgen Konczak. Effects of a robot-aided somatosensory training on proprioception and motor function in stroke survivors. *Journal of NeuroEngineering and Rehabilitation*, 18(1), 2021.

IBRO 2023 — 11th IBRO World Congress of Neuroscience, GRANADA, SPAIN · 9-13 September · 2023

California-Catalonia Program BALSELLS FELLOWSHIP

Supported by NIH R01HD062744, NIDILRR 90REGE0010

NIH Grant P41 EB018783, Stratton VA Medical Center, NYS SCIRB C33279GG, C38338GG