2.5.1.e
Extraneural Recordings Enable the Decoding of Intrinsic Hand Movements in Transhumeral Amputations

Bahareh Ahkami[1,2], Enzo Mastinu[1,2], Eric Earely[1,2], Max Ortiz-Catalan[1,2,3,4]

[1]Center for Bionics and Pain Research, Gothenburg, Sweden. [2]Department of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden. [3]Operational Area 3, Sahlgrenska University Hospital, Gothenburg, Sweden. [4]Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden

BACKGROUND
Myoelectric prostheses restore limited hand function to individuals with upper limb amputation. The lack of prosthetic finger control indicates that there is a long way for prosthetic hands to be comparable to a biologic hand. Recent studies showed that primitive sensory feedback can be restored via extraneural electrodes placed around the nerves[1,2]. However, the capability of extraneural electrodes, such as cuffs, to record extraneural signals usable for decoding hand movements has not been demonstrated.

AIM
To investigate the feasibility of using extraneural signals to decode intrinsic hand movements in upper limb amputations.

METHOD
In three participants with transhumeral amputations, electroneurographic (ENG) signals were recorded using implanted cuff electrodes optimized for recordings[3]. Electromyographic (EMG) signals were also recorded using two implanted electrodes in the biceps and triceps muscles[1]. Participants trained the execution of phantom movements with a simple graphical interface showing the magnitude of each ENG signal in real-time. The training aimed at allowing the participants to identify how to execute movements resulting in ENG activity related to the executed phantom movements. Participants were then asked to execute four gross arm movements (hand open and close, and elbow flexion/extension) and up to five finger movements related to the recorded nerve (ulnar or median).

RESULTS
Offline analysis showed that intrinsic hand movement discrimination errors using ENG signals alone for 3 participants were 17%, 21.8%, and 16%, and when only EMG signal used it was 27%, 40%, and 13%. The error was reduced to 2%, 17.5%, and 4% when ENG and EMG signals were combined. This finding was consistent with the real-time performance, where the classification error of EMG + ENG was significantly lower than EMG or ENG alone ($p<0.01$). Our findings indicate that the combination of ENG and EMG signals can be used to decode hand and finger movements in individuals with transhumeral amputation.

DISCUSSION AND CONCLUSION
One major unsolved problem in prosthetics is to effectively use neural signals to enable the control of artificial limbs. Our results suggest that ENG signals recorded by cuff electrodes can be a valuable source of information for decoding intrinsic hand movements at transhumeral amputation levels. However, the reliability of such ENG-based control still needs to be tested in daily life, which requires specialized electronics as ENG signals are considerably smaller than EMG.

REFERENCES
1. Ortiz-Catalan et al. 2020, *N. Engl. J. Med.*
2. Graczyk et al. 2018, *Sci. Rep.*
3. Ortiz-Catalan et al. 2013, *J. Neuroeng. Rehabil*

ACKNOWLEDGEMENTS: Research supported by the Promobilia Foundation, the IngaBritt and Arne Lundbergs Foundation, the Swedish Innovation Agency (VINNOVA), the Swedish Research Council (Vetenskapsrådet).