

## Comparison of EMG-Force Calibration Protocols for Myoelectric Control of Prostheses

Z. Zhu<sup>1</sup>, J. Li<sup>1</sup>, C. Dai<sup>2</sup>, C. Martinez-Luna<sup>3</sup>, B. McDonald<sup>3</sup>, T. Farrell<sup>3</sup>, X. Huang<sup>1</sup>, E. A. Clancy<sup>1</sup>

1. Worcester Polytechnic Institute, Worcester, MA, USA

2. Department of Electrical Engineering, Fudan University, Shanghai, China

3. Liberating Technologies Inc., Holliston, MA, USA

{zzhu2, jli6}@wpi.edu, chenrundai@fudan.edu.cn, {carlos.martinez, Benjamin.McDonald, todd.farrell}@liberatingtech.com, {xhuang, ted}@wpi.edu

**Introduction:** The surface electromyogram (EMG) is used as a control source for limb prostheses. When developing hand-wrist prostheses control schemes with able-bodied subjects, it is common to relate forearm EMG to hand-wrist forces/moments using supervised models. However, subjects with unilateral limb absence cannot produce such forces. Thus, we contrasted use of “output” alternatives from the force generated by the sound side in “mirror” movements [1–2], or directly using a target followed with their limb-absent side [3–4].

**Methods:** Data were collected at 2048 Hz from 12 able-bodied subjects (6 male, 6 female). Bipolar EMG electrodes (16) were secured around their dominant distal forearm. Each wrist was secured to a separate three-axis load cell to measure wrist force/moment. Each hand was secured to a separate one-DoF load cell to measure handgrip force. Subjects performed constant-posture, 1-degree-of-freedom (DoF) random force target [0.75 Hz, white, bandlimited, 40 s, –30 to 30% maximum voluntary contraction (MVC)] tracking trials of: a) wrist radial-ulnar deviation (Rad-Uln), b) wrist pronation-supination (Pro-Sup) or c) hand open-close (Opn-Cls). Different modes of real-time visual feedback were studied: 1) subjects tracked the target only using real-time force feedback from their dominant limb (EMG-Force<sub>Dom</sub>); 2) subjects tracked the target with only their dominant limb, with no force feedback provided (EMG-Target<sub>Dom</sub>); 3) subjects tracked a pair of symmetrical targets (one per side), with force feedback from the non-dominant side shown in both displays (mirror visual feedback: EMG-Force<sub>ND</sub>); 4) EMG data from the prior mode was re-used off-line and related to the target (EMG-Target<sub>MVF</sub>). Each trial combination (a–c vs. 1–3) was repeated twice.

Raw EMG were highpass filtered (5th-order Butterworth,  $f_c=15$  Hz) to remove motion artifact, notch filtered at the power-line frequency (2nd-order IIR at 60 Hz, notch bandwidth of 1 Hz) and rectified. Hand/wrist force/moment was normalized to MVC. Then, all signals were decimated (lowpass filter:  $f_c=16$  Hz, Chebyshev Type I, 9th-order, 0.05 dB peak-to-peak passband ripple) to 40.96 Hz. Since feedback-based force tracking incurs a time latency of up to approximately 200–300 ms, this alignment latency ( $k$  samples) was estimated by maximum cross-correlation between Force-Force (or Force-Target). Then, EMG-Force/Target was modeled as below, where  $Q=20$  was the order of the linear dynamic model,  $E=16$  was the number of electrodes,  $m$  was the decimated sample index, and  $EMG\sigma$  were the processed EMG:

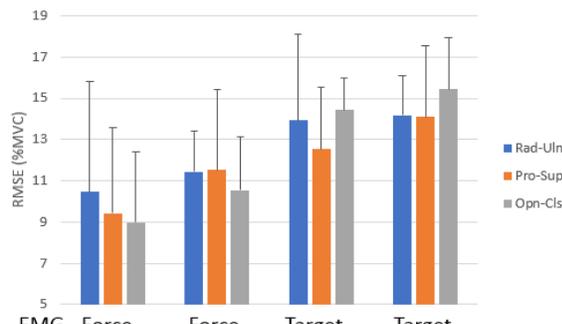


Fig. 1 RMSE of four estimation modes for the three DoFs.

$$Force[m] = \sum_{q=0}^Q \sum_{e=1}^E c_{e,q} EMG\sigma_e [m - q - k].$$

The first trial trained coefficients via the linear least squares pseudo-inverse method ( $Tol = 0.1$ ), and the second trial tested RMSE between estimated and measured force/target. Then the two trials were flipped for cross-validation and their average was reported.

**Results:** Fig. 1 shows the RMSE of the four estimation models for the three DoFs. A two-way repeated measures analysis of variance (RANOVA) was computed with the

factors of *feedback* (EMG-Force<sub>Dom</sub>, EMG-Force<sub>ND</sub>, EMG-Target<sub>Dom</sub>, EMG-Target<sub>MVF</sub>) and *DoF* (Rad-Uln, Pro-Sup, Opn-Cls). Only *feedback* was significant ( $F(3,33) = 14.9, p < 10^{-3}$ ), without interaction. *Post hoc* pairwise comparison of *t*-tests with Bonferroni correction found that conventional EMG-Force<sub>Dom</sub> had significantly lower RMSE than EMG-Target<sub>Dom</sub> ( $p = 0.008$ ) and EMG-Target<sub>MVF</sub> ( $p = 0.001$ ); and EMG-Force<sub>ND</sub> had significantly lower RMSE than EMG-Target<sub>MVF</sub> ( $p < 10^{-3}$ ).

**Discussion:** In this experiment, feedback from ipsilateral force, contralateral force and target movement in able-bodied subjects were contrasted. Using the contralateral limb for force feedback had similar performance as using conventional ipsilateral limb feedback, and much better performance than using the target with no feedback. Mirror movement did not enhance target estimation. Symmetry is an intrinsic human characteristic [5], but target tracking is a highly demanding task which needs practice. However, for limb-absent subjects, either congenital or traumatic amputation leads to amyotrophy or neuron damage and may influence the symmetric movement. Thus, further testing on limb-absent subjects is necessary to evaluate the performance of different EMG-force calibration protocols.

#### ACKNOWLEDGMENTS

Supported by Eunice Kennedy Shriver National Institute of Child Health & Human Development under grant R42HD076519. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

#### REFERENCES

- [1] J. L. Nielsen, S. Holmgaard, N. Jiang, K. B. Englehart, D. Farina, and P. Parker, "Simultaneous and proportional force estimation for multifunction myoelectric prostheses using mirrored bilateral training," *IEEE Trans. Biomed. Eng.*, vol. 58, no. 3, pp. 681–688, 2011.
- [2] S. Muceli, N. Jiang, and D. Farina, "Multichannel surface EMG based estimation of bilateral hand kinematics during movements at multiple degrees of freedom," presented at the 32nd Ann. Int. Conf. IEEE EMBS, Buenos Aires, Argentina, 2010.
- [3] A. Ameri, E. J. Scheme, E. N. Kamavuako, K. B. Englehart, and P. A. Parker, "Real-time, simultaneous myoelectric control using force and position-based training paradigms," *IEEE Trans. Biomed. Eng.*, vol. 61, no. 2, pp. 279–287, 2014.
- [4] A. Ameri, E. N. Kamavuako, E. J. Scheme, K. B. Englehart, and P. Parker, "Support vector regression for improved real-time, simultaneous myoelectric control," *IEEE Trans. Neural Sys. Rehabil. Eng.*, vol. 22, no. 6, pp. 1198–1209, 2014.
- [5] S. P. Swinnen, "Intermanual coordination: From behavioral principles to neural-network interactions," *Nature Rev.*, vol. 3, pp. 350–361, 2002.

## I Introduction

### Motivation

- The surface electromyogram (EMG) is used as a control source for limb prostheses.
- Relate forearm EMG to hand-wrist forces/moments by supervised models.

### Problem

- People with unilateral limb absence (trans-radial) cannot produce such forces.
- No "output" for EMG-Force models.

### Solution

- Able-bodied subjects simulated amputees condition to find the best alternative feedback.

## II Preparations

- Twelve able-bodied subjects (6 males, 6 females).
- Sixteen bipolar electrodes around proximal forearm.
- Hand cuffed to load cell (Fig. 1).
- Hardware (Amplifier, ADC...)/ Software (LABVIEW, MATLAB).

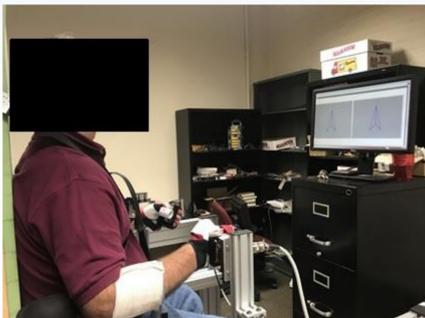
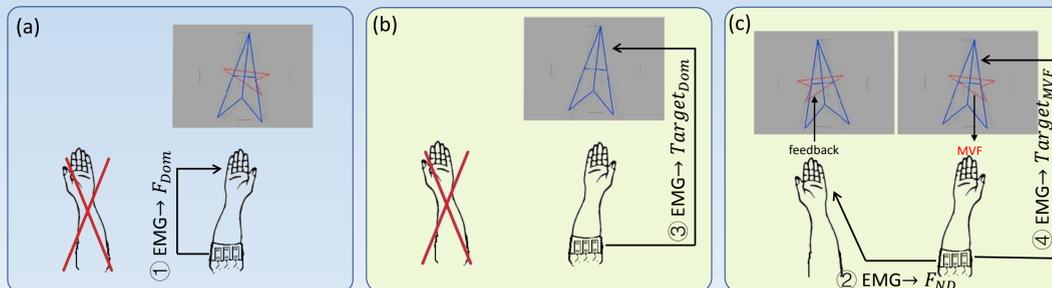


Fig. 1. Data collection apparatus for able-bodied.

## III Protocols

- DoFs: Rad-Uln:  Pro-Sup:  Opn-Cls: 
- MVC tasks.
- Dynamic Target tracking trials (40s, 2 trials,  $\pm 30\%$  MVC):** The dynamic target was a 0.75 Hz band-limited, white and uniform random process between  $\pm 30\%$  MVC (two directions) corresponding to the utilized motion.

Conditions	Models
(a) Only dominant limb tracked the target, with a real-time visual feedback from dominant force.	Reference: ① EMG-Force <sub>Dom</sub>
(b) Only dominant limb tracked the target, without real-time visual feedback.	③ EMG-Target <sub>Dom</sub>
(c) Both limb tracked a pair of mirror target, with real-time force feedback from non-dominant limb shown in both displays (MVF provided).	② EMG-Force <sub>ND</sub> ④ EMG-Target <sub>MVF</sub>



## V Results

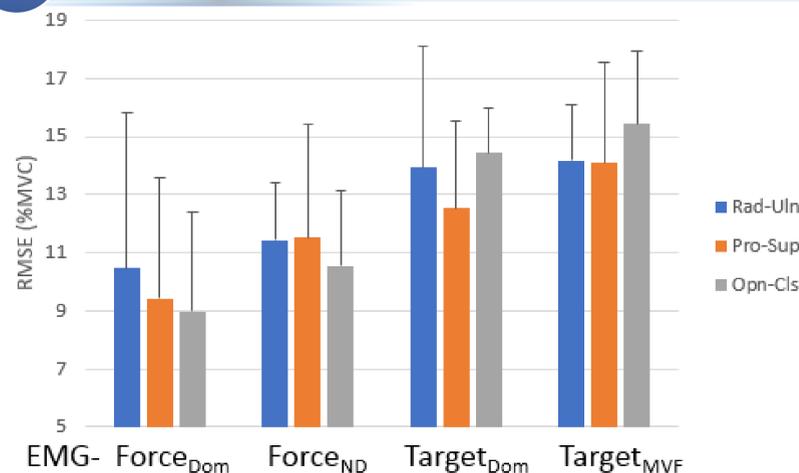
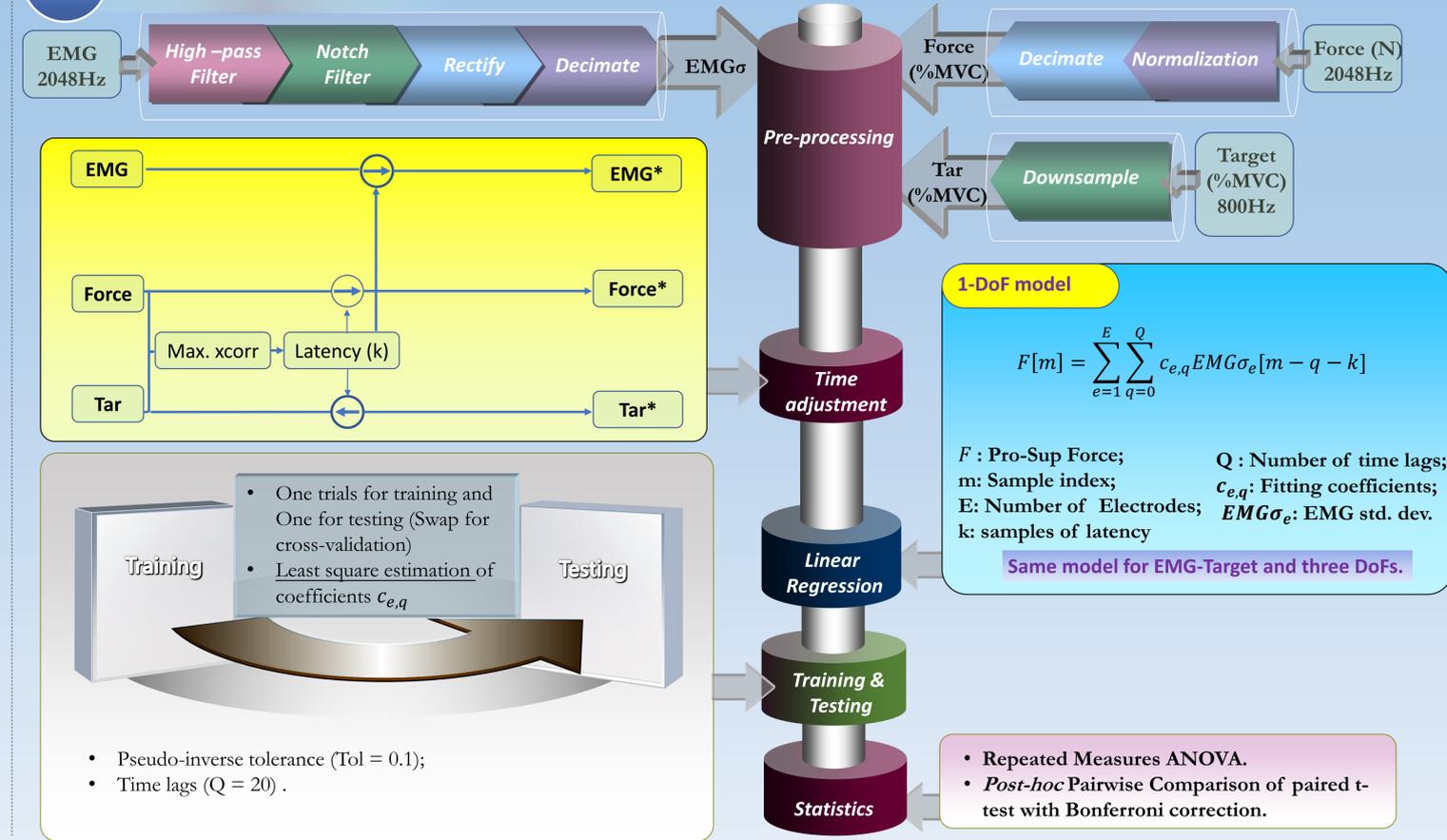


Fig. 2 Mean  $\pm$  std. of three DoFs and 4 estimations (left) and an example of four estimations of Rad-Uln, sub 02, set 01 (right).

- A 2-way RANOVA found no significant difference between three DoFs, but estimations were significant ( $p < 10^{-3}$ ).
- EMG-Force<sub>ND</sub> has similar performance as EMG-Force<sub>Dom</sub>, and better than EMG-Target<sub>Dom</sub> and EMG-Target<sub>MVF</sub>.
- MVF didn't improve the performance when using Target as estimation.

## IV Preparations



## VI Discussion

- Feedback from ipsilateral force, contralateral force and target movement were contrasted, able-bodied subjects simulated what amputees faced the conditions.
- Using the contralateral limb for force feedback had similar performance as using conventional ipsilateral limb feedback, and much better performance than using the target.
- Mirror movement didn't enhance target estimations.
- Symmetry is an intrinsic human characteristic, but target tracking is a highly demanding task which needs practice.
- Further testing on amputees with different EMG-Force/Target calibration protocols: more challenge (neuron damage, amyotrophy.....).

### ACKNOWLEDGMENTS

Supported by Eunice Kennedy Shriver National Institute of Child Health & Human Development under grant R42HD076519. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.