Comparing different vibrotactile strategies to encode motor units’ activation states

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Introduction

Sensory feedback encoding motor units (MUs) activity could benefit human motor augmentation (Eden et al. 2022) by helping participants to flexibly and independently recruit distinct MUs (Bräcklein et al. 2020), whose modulation could be used to control supernumerary effectors. Somatosensory feedback has the advantage, over other sensory modalities, of providing unobtrusive but meaningful information through a fast sensory pathway (Crevecoeur et al. 2016). Hence, in the present study, we validated two different vibrotactile strategies (i.e. spike strategy and continuous strategy) designed to encode the firing rate frequency of two different MUs active at the same time. The simulated activity of each unit is transmitted by a different stimulator. A psychophysics experiment based on a two-alternative forced-choice paradigm was run to verify which among the two presented approaches allows the subject to easily understand the different activation frequencies of MUs.

Methods

Two groups (one per strategy) of 5 different participants took part in the study. The two tested strategies shared a similar experimental setup. Two stimulators (i.e., two eccentric rotating mass motors) were activated at the same time for 3 seconds in the spike strategy condition, and 1.5 seconds in the continuous one. Participants were asked to report which stimulator (i.e., right (RS) or left stimulator (LS)) was vibrating with higher frequency. We simulated the MU activity within a range of 4-18 Hz and with differences in frequency between stimulators (i.e. RS’s frequency – LS’s frequency) in the range of -3 to 3 Hz. The obtained data was then used to fit a classic S-shape sigmoid curve.

Spike strategy

The spike strategy is a bio-feedback consisting of the activation and deactivation of stimulators in a time-locked fashion with the activity of the simulated MU. The experiment consisted of two blocks: one with stimulators in two different arms (figure 1, A) and a second with both stimulators on the same arm (figure 1, B). The blocks’ order was pseudorandomized.

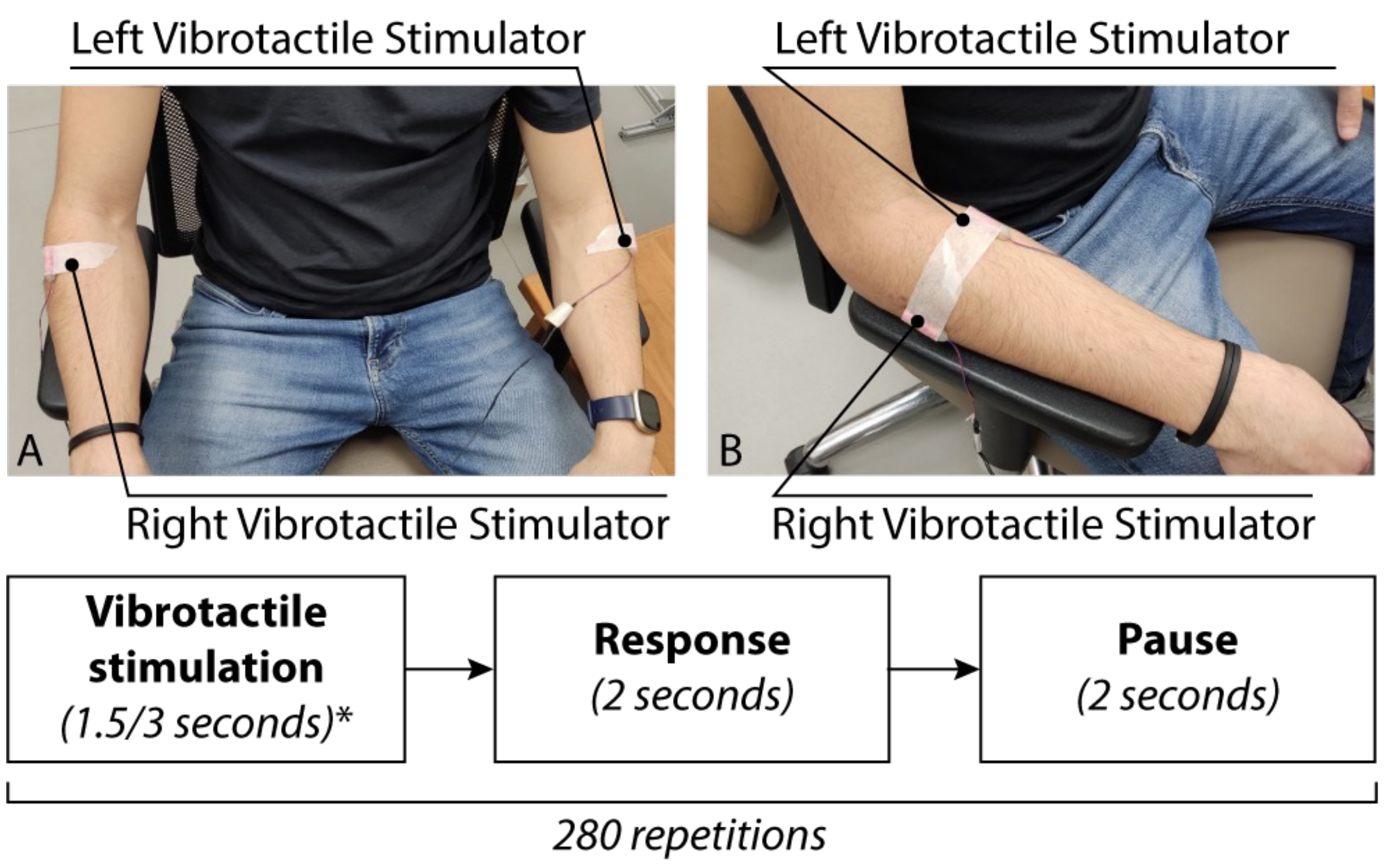

Figure 1. *TOP, the two stimulator’s configurations: different forearms (A) and same forearm (B), with stimulators always placed on the C7 dermatome. BOTTOM, schematic representation of the psychophysics protocol adopted in both strategies.*

Results

For each curve, the Esteem Accuracy (EA) and the corrective 95% confidence interval (CI) were calculated. EA is a measure proportional to the inverse of the curve’s slope in correspondence of the Point of Subjective Equality, with a smaller indicating better feedback performance. The EA values in the spike strategy were: 10.43 Hz (CI 8.10-12.77 Hz) and 5.96 Hz (CI 4.56-7.36 Hz) respectively for the configuration with one arm (Figure 3, A) and different arms (Figure 3, B). While for the continuous strategy, EA was 2.85 Hz (CI 2.26-3.43 Hz) for the flat approach (Figure 3, C) and 2.70 Hz (CI 2.51-2.8868 Hz) for the percentage approach (Figure 3, D).

Conclusions

Usually, two MUs active together have a firing rate difference of 1-2 Hz (Bräcklein et al. 2020). In that range, the spike strategy shows poor performance in both stimulators’ configurations, reaching an accuracy of ~50-60% with 1 Hz difference. Still, the spike strategy with one motor for each arm works slightly better than the other configuration. This is most evident in the range from -2 to -1 Hz. A possible reason for the poor performance, despite the simple feedback encoding, could be the type of motor used. The eccentric rotating mass motors are characterized by slow dynamics, which is a critical aspect for a feedback that requires to be time-locked with the neurons’ activity, and should therefore start and stop its movement in a small time window. As regard the continuous strategy, results demonstrate better performance (~80% accuracy at 1 Hz difference) compared to the spike strategy, with both increment approaches, and it seems to be the preferable choice with this type of actuator. Despite the results obtained, given the close correlation between the spike strategy and the MU’s activity, it may be worth trying to evaluate the quality of the feedback with a class of more performant motors (e.g. linear actuators).

Continuous strategy

This strategy consists in a continuous vibration which could range from 40 to 230Hz. The relation between the simulated MUs’ action potential frequency and the stimulator’s continuous vibration was obtained with two different increment approaches: the flat approach, where the increase between steps was fixed (i.e., 13.6Hz, Eq. 1), and the percentage approach, where each frequency value was obtained by increasing the previous one by 13% (eq. 2). The stimulators were always placed in two different arms (Figure 1, A) and the two increment approaches were tested in different blocks with pseudorandomized order.

$$f_f(MU_f) = 40 + 13.6 * (MU_f - 4) \quad (1)$$

$$f_p(MU_f) = 40 * (1 + 0.133)^{MU_f - 4} \quad (2)$$

Equation 1. *Describes the relationship between the simulated MUs’ frequency, and the corresponding continuous frequency in the flat approach.* **Equation 2**. *Describes the relation between the simulated MUs’ frequency, and the corresponding continuous frequency in the percentage approach. MUf is an integer number between 4-18.*

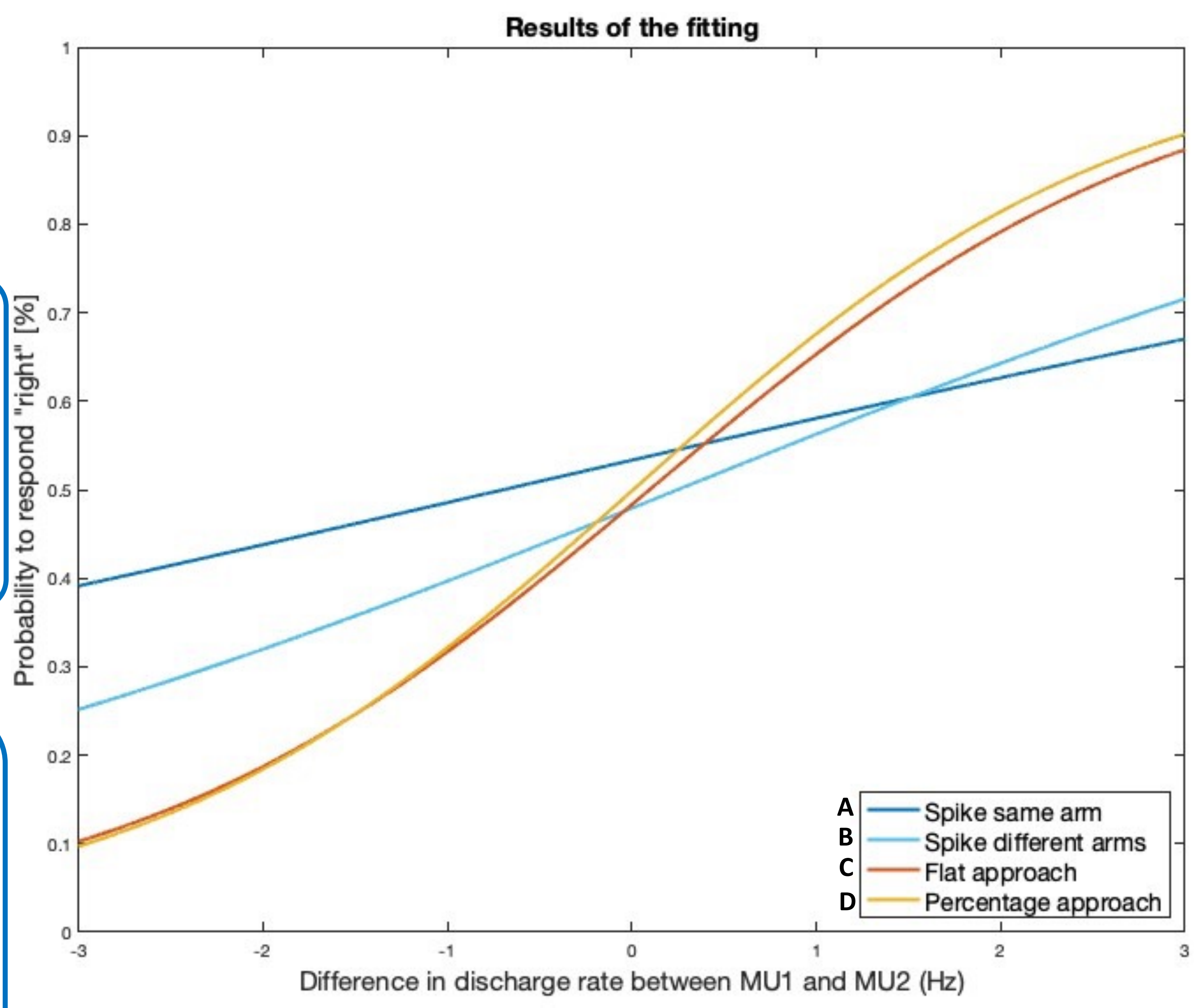

Figure 3. *Curves were obtained by fitting the data of all subjects. A-B are the results of the spike strategy, in the same arm configuration (A) and different arm configuration (B). C-D are the results of the continuous strategy for the flat increment (C) and for the percentage increment (D). X-axis is the difference in the activation of the stimulators, computed as RS - LS, and expressed in Hz. Y-axis is the chance that participants report the RS as the one with the higher vibration intensity.*

Eden, J., Bräcklein, M., Ibáñez, J., Barsakcioglu, D. Y., di Pino, G., Farina, D., Burdet, E., & Mehring, C. (2022). Principles of human movement augmentation and the challenges in making it a reality. *Nature Communications*, *13*(1), 1–13.Bräcklein, M., Barsakcioglu, D. Y., Ibáñez, J., Eden, J., Burdet, E., Mehring, C., & Farina, D. (2022). The control and training of single motor units in isometric tasks are constrained by a common input signal. *Elife*, *11*, e72871.
Crevecoeur, F., Munoz, D. P., & Scott, S. H. (2016). Dynamic multisensory integration: somatosensory speed trumps visual accuracy during feedback control. *Journal of Neuroscience*, *36*(33), 8598–8611.