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# Decoding of Coordinated Hand and Arm Movements

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*Introduction:* Natural reaching entails the coordinated movements of joints distributed over the entire upper limb – including the arm and hand. Furthermore, individual neurons in motor cortex carry "multiplexed" signals associated with the coordinated control of both hand and arm movements [1]. Despite this, brain-computer interface (BCI) decoders for restoring upper limb movement have been trained with isolated, sequential movements of the arm, wrist, and hand [2]. Decoders trained on isolated movements do not lead to smooth, quick movements seen in native arm use during tasks requiring coordinated movements [2]. Additionally, previous work in non-human primates has demonstrated tuning to movement speed in addition to velocity [3,4]. Here we show that training on a task requiring coordinated movements and including a normalized speed term in the decoder, that accounts for hand, wrist and arm movements, improves BCI control during a coordinated grasp and transport task.

*Material, Methods and Results:* Data was collected from an individual (C1) with a C4 ASIA D spinal cord injury who was participating in an ongoing clinical trial (NCT01894802) for intracortical BCI control of a robotic prosthetic limb conducted under an FDA Investigational Device Exemption. They completed a 7-degree of freedom (DOF) grasp and transport task in Virtual Reality (VR). The DOFs correspond to hand translation (3D), wrist orientation (3D), and grasp aperture (1D). All DOFs were controlled simultaneously. The task was completed using two motor decoders: a velocity-based (V) decoder as used previously [1] and a new version that added a speed term (V+S). The participant failed the task if any phase of the task timed out (> 10 s) before they achieved the target posture in all DOFs. The decoders were trained and tested in a two-step training protocol used previously [1,2]. The computer assistance is titrated until the user has unassisted control of the VR arm. All results presented are for the unassisted trials.

Over 4 sessions, the participant attempted the simultaneous 7DOF grasp and transport task 180 times with each decoder. They successfully completed the entire task 50 and 80 times for V and V+S decoders, respectively (2-tailed 2-proportion z-test: $p = 9.95e\text{-}4$; Cohen's h: $h = 0.349$). For those successful trials, the task completion time on average was 21.52 s ($\sigma = 4.11$) and 19.24 s ($\sigma = 5.05$), respectively (2-tailed 2-sample t-test: $p = 5.9e\text{-}3$; Cohen's d: $d = 0.482$). Figure 1 shows task completion times for each successful trial, grouped by the decoder used.

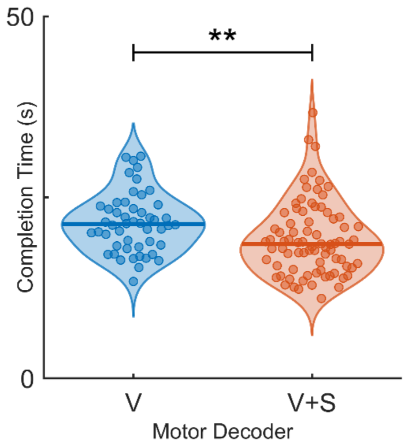


Figure 1: Task completion times for each motor decoder. The dots correspond to the completion times for individual trials. The V+S decoder shows significant improvement in task completion time compared to V ($p < 0.01$ and "medium" effect size).

*Conclusion and Discussion:* These results are promising evidence for the benefit of adding a speed term to the decoder when completing coordinated tasks. The participant completed more tasks successfully ($p < 0.001$ and "small" effect size) and faster ($p < 0.01$ and "medium" effect size) with the addition of a speed term. This important addition to decoder design promises to improve the smoothness and naturalness of BCI-controlled prosthetic arms for activities of daily living.

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