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A Closed-Loop Prosthetic Hand as a Model Sensorimotor Circuit

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Abstract

We present a novel manipulandum for understanding the sensorimotor processes involved in object grasping. We have developed a closed-loop prosthetic hand, with 2 degrees of control and 32 channels of vibrotactile feedback of fingertip forces and finger positions. In order to understand this model sensorimotor circuit we first tackle two sub-problems: (Q1) Do we integrate artificial sensory feedback (vibrotactile) with our other modalities (vision, proprioception) in a statistically optimal manner based on sensory uncertainty? We run subjects through a pursuit tracking task with noisy visual and vibrotactile cues to cursor location, and describe the resulting trajectories with a Kalman filter model; and (Q2) Are grasp trajectories and temporal force profiles a predictable function of the actuation commands that control the hand and the available feedback? We run subjects through a new tracking task where the grasp size and force on an object are modulated, and compare the resulting trajectories to those predicted by the optimal feedback control (OFC) framework.

Motivation

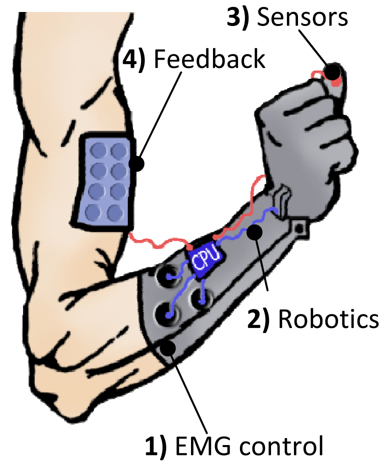
Modern hand prostheses can often feel 'clumsy' [1]. We hypothesise that this is due to the absent senses of touch and proprioception. Indeed, attempts to augment prostheses with force feedback have proven subjectively to be of benefit [2]. We therefore close the loop with artificial sensory feedback.

Using this closed-loop system our aims are twofold: (1) to develop a hand-prosthesis that quantifiably improves object grasping ability, and (2) to uncover the underlying cognitive processes in object grasping.

Methods

In collaboration with prosthesis developer Touch Bionics, we fit subjects with the **i-limb**, a state-of-the-art prosthetic hand, and an array of vibrating motors to communicate feedback from force and position sensors to the wearer.

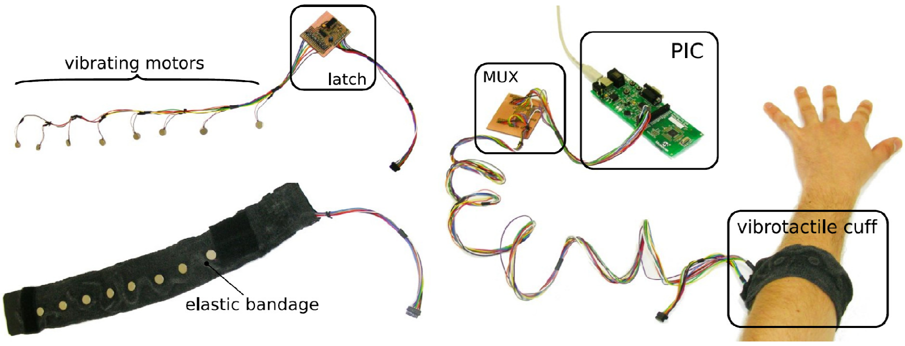
In this closed-loop setup, by comparing hand trajectories and force profiles under different experimental conditions we can isolate the different components of the sensorimotor circuit. We have two conditions for actuation (the healthy human hand; and replacing the human hand with the prosthesis) and two conditions for sensory feedback (natural feedback; and replacing natural feedback with vibrotactile feedback). For the latter we use fingertip anaesthesia, force sensors and our vibrotactile array.



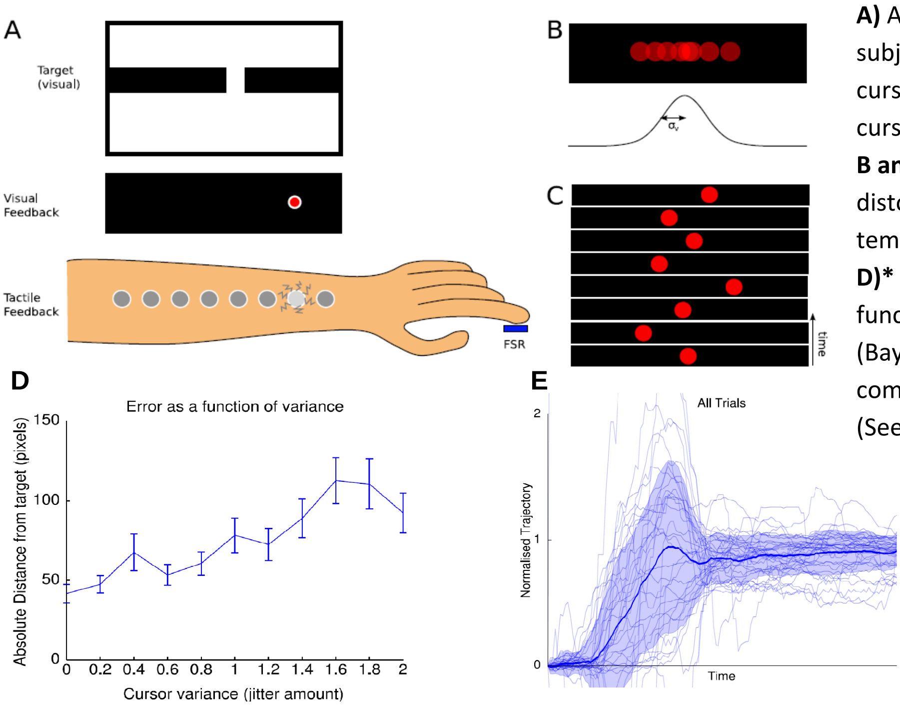
We are presently conducting experiments (Q1) and (Q2), see abstract, results to be presented.

Vibrotactile Array

We have developed a vibrotactile array of 32 vibrating motors, each delivering 32 levels of vibration intensity. Sampling sensors and updating the motors at 200Hz, we have a high resolution, responsive sensory channel for fingertip forces and positions. This feedback is accessible for experimental manipulations unlike our native tactile and proprioceptive senses.



(Q1) Do humans optimally integrate sensory information, regardless of the modality it is presented in?



A) An experimental paradigm in which the subject must pursue a target by moving a cursor. Visual and vibrotactile cues of the cursor location are provided.

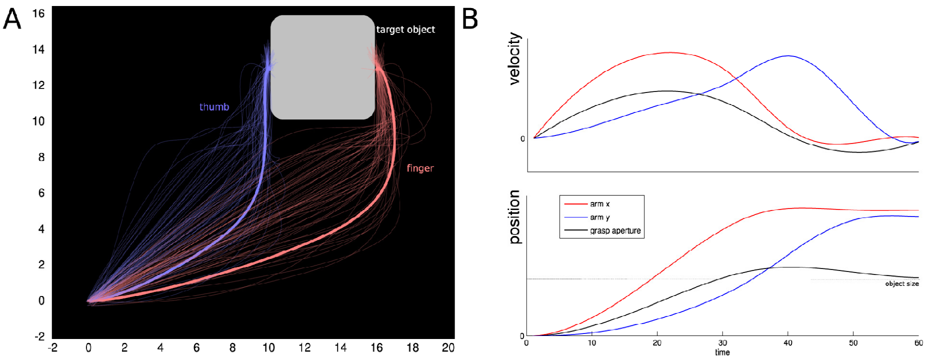
B and C) The visual and tactile cues are distorted by noise, either spatially or temporally.

D)* Human performance degrades as a function of cue variance. Statistically optimal (Bayesian) models of cue integration are compared to human performance in the task. (See [3])

E)* We analyse the chosen trajectory and compare it to computational models of temporal integration of statistical information.

*preliminary data

(Q2) Is human motor control 'optimal' with respect to available sensory feedback?



A) The 'optimal' path of thumb and forefinger when grasping an object. We model the human hand and assign a cost function: cost increases with energy expended (excessive muscle activity), collision with the target object and endpoint kinematic variables, using optimal feedback control (see [4])

B) The trade-off between these cost terms results in smooth trajectories with bell shaped velocity profiles, similar to healthy human behaviour.

References

[1] Zhou et al. *J Neurophysiology*, 2007 [2] Cipriani et al. *Robotics, IEEE Transactions on*, 2008.
[3] Kording et al. *Nature*, 2004. [4] Todorov et al. *Nature Neuroscience* 2002.