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Short Communication

Need for Somatotopically Relevant Tactile Sensory Feedback for Neuromusculoskeletal Prosthesis Users to Normalize Grasping Coordination

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DESCRIPTION

According to Bayesian models of sensorimotor learning, humans perform motor tasks in a statistically optimized fashion [1-3]. Indeed, during any motor task, our internal estimate about the task (i.e., the posterior) is constantly updated by combining previous known information about that task (i.e., the prior) with evidence from any sensory feedback available (i.e., the likelihood from observations). In simpler words, when playing tennis and receiving a ball our brain constantly tries to estimate where the ball is going to by combining information about the previous location of the ball with fresh observations from visual, auditory and haptic sensory feedback.

From this it derives, confirmed by strong empiric evidence, that if a sensorial source suddenly presents a high variability, or noise, then our brain would automatically disregard that information in favor of other more reliable sensorial sources. First problem, tactile sensory feedback is almost completely lacking in users of conventional myoelectric hand prostheses, forcing these individuals with upper limb amputation to rely almost exclusively on visual feedback.

The control of electrically-powered prostheses conventionally relies on myoelectric sensors placed on the surface of the stump. Signals picked up from these sensors can be used to drive the prosthesis in a one-muscle one-movement simplistic approach (e.g., flex biceps to close the prosthetic hand). However, there are major well-known challenges related to the use of surface myoelectric sensors, such as susceptibility to electromagnetic noise, motion artifacts, and interface impedance changes due to environmental conditions. Second problem, myoelectric control achieved by conventional surface sensors is known to be hardly reliable and repeatable (i.e., high variability in the prior).

As a consequence of these first two problems, the grasping behavior of prosthetic hand users is still far from that of a biologically intact hand. This can be easily seen in the general reliability of the control as well as in the coordination of grip and lift forces when interacting with objects. A common test to assess motor coordination during grasping is the pick-and-lift task. Typically, able-bodied adults show a linear and balanced relation between grip and lift forces [4,5], while prosthetic hand users show a step function where grip force reaches its peak before the lift force (i.e., they first squeeze the object then they lift it).

Osseo Integration (OI) has been proposed and recognized as a valid alternative for the attachment of upper and lower limbs prostheses [6,7]. It inherently provides a direct skeletal attachment which can be used to 1) connect the prosthesis to the body avoiding the known issues related to conventional socket-attachment, and 2) transfer loads directly to the skeletal system. Moreover, there is enough evidence to support the fact that 3) individuals with OI have access to another sensorial source, namely osseoperception [8-10]. Osseoperception refers to an improved mechano-sensibility associated with the osseointegrated implant compared to conventional socket-attached prostheses. Lastly, 4) OI also enables the long-term use of sub-cutaneous implanted myoelectric sensors for improved prosthetic control, opening up to the so called neuromusculoskeletal prosthesis [11,12]. Third problem, it is unknown whether having access to a more reliable source for control as well as to richer sensorial information (i.e., visual +osseoperception) would lead to more natural grasping behavior.

The three problems aforementioned provided the context and the rationale for the study treated by this commentary [13]. In this study we involved 3 users of neuromusculoskeletal prosthesis [12]. These research subjects constitute a quite unique population of prosthetic users for whom the robotic arm is simultaneously attached to the skeletal system via osseointegration, and to nerves and muscles via sub-cutaneous myoelectric sensors. For the sake of the intended comparison, these subjects alternated their myoelectric control between surface and implanted sensors. Therefore, assuming a superior controllability offered by the implanted myoelectric sensors, we hypothesized that such setup would entail better grip force modulation, reliability, and motor coordination than conventional surface sensors.

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At first, superior controllability was investigated and confirmed. When using the implanted sensors, significant improvements were indeed found in the modulation of the grip force and its reliability. However, these improvements failed to improve (or normalize) the motor coordination, surprisingly worsening the relationship between grip and lift forces observed in surface electrodes configuration. Even if proven functional and reliable, prosthetic control via implanted sensors and OI still depended highly on visual feedback. These findings indicate that visual, auditory, and osseoperceptive incidental sensory feedback available to these particular subjects was insufficient for restoring their natural grasp behavior and suggests the idea that supplemental tactile sensory feedback is needed to learn and maintain the motor tasks internal representation.

This conclusion opened up to another study that we recently published on Scientific Reports [14]. In this study we investigated if closed-loop control achieved by somatotopically appropriate tactile sensory feedback (i.e., perceived in the phantom hand) could restore motor coordination during grasping. Hence, we enrolled the same subjects of the previous study and we repeated the same motor coordination investigation while providing real-time, tactile sensory feedback via electric pulses conveyed on the arm nerves. Moreover, we also studied the effects on the coordination of uncertainty in the task by unexpectedly changing weight of the test object. For this part of the study, we tried to replicate the work from Jenmalm et al. with non-amputees subjects [15].

Here, a closer-to-normal grasping behavior was observed. Our research subjects were overall faster in performing the task when provided with tactile sensory feedback. Moreover, they showed a considerably shorter delay between the grip and lift forces, ultimately exhibiting a more linear (and more normal) relation between these forces. Additionally, it was found overall a fast adaptation to the tactile sensory feedback. Connecting back to the Bayesian models of sensorimotor learning, such fast adaptation might indicate that the variability in the sensory feedback, as the compound information from all sensorial sources available, was perceived comparable to the internal prior estimate of the task, or at least small enough to trigger considerable behavioral changes in these subjects [2,16,17]. The performance of subject S3 supports this hypothesis: he was already a skilled prosthetic user with a potentially robust own estimate for whom tactile feedback had no positive effect.

CONCLUSION

This package of work supports the intuitive idea that tactile sensorial information is required for normal grasping behaviours, and additionally it justifies the need for tactile somatotopic sensory feedback in hand prostheses. Now that advanced neuroprostheses are becoming a clinical reality, it is mandatory to investigate how long-term, home-use of such devices can promote robust behavioral changes towards a more natural use of artificial hands.

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