Embodying prostheses – how to let the body welcome assistive devices

Comment on "The embodiment of assistive devices – from wheelchair to exoskeleton" by Pazzaglia and Molinari

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A growing body of research has focused on the development of assistive devices to improve the recovery and ameliorate the quality of life of people suffering from spinal cord injuries (SCI). In their stimulating and timely paper, Pazzaglia and Molinari [1] review the significant progress made by biotechnology studies in providing increasing sophisticated assistive tools such as robotic legs (e.g., prostheses and exoskeletons) that extend the functionality of patients' bodies. However, despite this extraordinary technological effort [2], it remains uncertain how these devices can be appropriately embedded into the mental representation of the body. Here, we wish to amplify the points raised by Pazzaglia and Molinari by discussing three challenges facing work on embodying prostheses raised by experimental research on body representation.

Pazzaglia and Molinari discuss prostheses in relation both to tool use and to illusions of ownership such as the rubber hand illusion. As has been noted by many authors, however, the subjective experience of wielding a tool is quite different from that of experiencing ownership over a limb [3,4]. Indeed, as Povinelli and colleagues [5] observe, in many cases the whole point of using a tool is that the action performed is something that the body cannot itself do (as when using a knife to slice vegetables) or which would be dangerous to do unaided (as when using a poker to stoke a fire). In such circumstances, it is critical to maintain the distinction between the tool and the body, in contrast to cases such as the rubber hand illusion in which the rubber hand appears to replace the participant's own hand [6]. Thus, it is important to consider whether a prosthesis is primarily meant to be a tool, a replacement for the missing limb, or both, as these might lead to very different implications for the design and functioning of prostheses.

A recent study by Luke Miller and his colleagues [7] is particularly intriguing in this context. They found that the plastic changes induced by tool-use on tactile distance perception are modulated by the morphological similarity between the tool and the body. When participants used a long, thin claw to grab objects, plastic changes were observed on the forearm – but not on the hand. In contrast, when they used a large hand-shaped tool, changes were observed on the hand – but not on the arm. This double-dissociation suggests that the embodiment of tools is not driven solely by their functionality, but also depends on the similarity in form between the tool and the body. This result has clear implications for prosthetics and exoskeletons in which the relation between the form of the prosthesis and that of the body varies widely. It also points to the critical role of vision in integrating the multiple sensory signals coming from the body and raises the question of how the functional utility of the prosthesis as a tool and its aesthetic character as a replacement for the lost limb should be balanced.

Another intriguing issue in the context of prosthetics is interoception, our perception of our body from the inside. Recent research has highlighted the critical role of interoception in representation of the body and self [8,9]. By their nature, prostheses are perceived exteroceptively – from the outside – rather than interoceptively – from the inside. This has potentially important implications for how they are experienced and incorporated into representations of the body. Two recent studies, however, have shown that interoceptive signals can enhance the embodiment of external objects [10,11]. Suzuki and colleagues [10] used augmented-reality to create a 'cardiac rubber hand illusion', finding that ownership was enhanced by visual modulation of the colour of the virtual

hand time-locked to the participant's heartbeats. Aspell and colleagues [11] found similar results using the full-body illusion. It is an intriguing possibility that such methods could be used to provide a form of interoceptive experience over prosthetic limbs or exoskeletons, allowing them to move beyond being a tool to being an integral part of the bodily self.

The final issue we wish to discuss concerns the time-course of embodiment. One puzzle about research on the plasticity of body representation is how to reconcile findings such as the rubber hand illusion showing rapid modulation of the experience of embodiment in simply laboratory settings with phenomena such as phantom limbs in which the experience of the body appears stubbornly resistant to alteration, even in the face of a massive change to the physical structure of the body [12]. Prosthetics limbs and exoskeletons are a particularly intriguing case in which plasticity might occur over multiple time-scales: rapidly as the user puts the prosthesis on and off on an hourly or daily basis, and slowly as the user develops expertise with and embodies the prosthesis over weeks or months of use.

This is an exciting time for research on assistive devices, as clearly described by Pazzaglia and Molinari. Together, the issues we have discussed show both the importance of experimental research on embodiment to the development of effective assistive devices and the fascinating implications of prostheses for understand basic issues about the nature of the bodily self. Understanding the mechanisms that determine the embodiment of external objects as part of our body is a pressing research goal. This will allow artificial devises such as prostheses and exoskeletons to be built so that they can be fully welcomed by the bodily self.

References

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Acknowledgments

MRL and LT were supported by a European Research Council Starter Grant (ERC-2013-StG-336050) under the FP7 to MRL. RS was supported by a studentship from the Economic and Social Research Council.