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Commentary

Smart Neuroprosthetics Becoming Smarter, but Not for Everyone?

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When Franconian knight Götz von Berlichingen (1480–1562) lost his right hand in 1504, he certainly could not gauge the possibilities that would have been available to him if he had lived today. And yet he was born into an auspicious time, in which the anti-scientific mediaeval decrees had been abandoned and the courage to use one's own intellect had been regained. In response to this he had two passive mechanical hand prostheses build corresponding to the highest engineering standards as he wished to continue as an active knight. Götz was rich and could afford it well. Had he been born today, there would be many other options available to him. But would he have tried them all?

Over the last few years, ideas, research and developments on intelligent neuroprosthetic concepts continue unabated. We have moved from the preclinical into the clinical stage, now able to electrically connect the brain, the spinal cord and the periphery by various tools advanced from medical technology, such as deep brain stimulation, brain arrays, cuff electrodes, and intrafascicular nerve and intramuscular electrodes [1]. With this “neuroprosthetic toolbox” [1] we are, now, able to learn via a neural network platform how to directly control intact muscles of the forearm by the brain's motor cortex and move the hand in tetraplegics again [2]. Likewise, robotic hands are equipped with sensors connected to the sensory cortex so that we can “feel” once more when the robotic hand is touched [3]. Nerves are connected to a remaining muscle that has previously been denervated to control a myoelectric prosthesis without needing to relearn how to move the missing limb [4].

These concepts are fascinating but are still at an early stage, very complex, expensive, invasive and often inapplicable outside the laboratory environment. In addition, there is an ethical discussion about these new techniques, which touch the innermost of our self: the brain that is plugged in and can be manipulated. Therefore, non-invasive approaches are also under development, with convincing results. Soekadar et al., for example, developed a fully independent hybrid electroencephalography/electrooculography-based brain/neural non-invasive, hand-exoskeleton approach, useful for tetraplegics outside of the laboratory [5]. Marasco et al. presented an automated neural-machine interface which vibrates the muscles used for control of prosthetic hands [6]. Hahne et al. came up with a regression-based concept that allows for simultaneous control of multiple functions of myoelectric hand prostheses [7]. These approaches may help amputees to better control prosthetic hand movements and are a big step forward for daily life activities of users of bionic hands.

Many further non-invasive approaches are under way now. Some concepts even go “back” to the roots. One possible way back might be through the technology of personalized mechanical 3D-printed prosthetics, e.g. for children with growing limbs. It seems that developers have begun to understand one basic take-home message: make the prosthesis as intelligent but simple as possible for the patient. Patient wishes and needs are, sometimes, very different and dependent on many factors of life and living conditions, for instance, age, income, country, religion, or profession. Hence, the development of intelligent neuroprosthetic tools should be a shared enterprise, where real-life wishes of patients and clinicians meet the enthusiasm and technological spirit of engineers. This, and only this, can help to create societal impacts.

And Götz? Although he had a much more complicated second, iron artificial hand, in which all fingers could be adjusted in all joints, he chose his first. It was mechanically simpler, but a more stable hand for use as a knight in everyday life, in which only the artificial thumb and two finger blocks could be moved. The 3D-printed polymer replica of this first passive hand prosthesis (Fig. 1) has shown convincing results for mechanical stability and simple actions of everyday use [8]. Interestingly, recent research showed that, when an opposable thumb is present, independent long fingers are not essential for a grasping hand in normal daily living activities [9]. We think that *Götz of the Iron Hand* would probably not have tried all of today's brain-machine-interface concepts, as he did not need them for his special situation. In his autobiography, which he dictated at the end of his life, Götz said, “*I prayed to God and thought to myself, even if I had twelve hands, and His grace and help would not be with me, it would be in vain. That is why I thought that if I had little spare by an iron hand, I wanted to be as efficient as any other frail man in the field*” [10].

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Fig. 1. 3D-printed polymer replica of the first, artificial “iron hand” of Götz von Berlichingen (see left side) based on the work in [8]. The replica was printed from computer-aided design (CAD) data by a 3D multi-material printer, Stratasys J750, that allows for the production of transparent components, offering insights into the mechanics of the hand. Picture credits: Offenburg University, Germany.

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