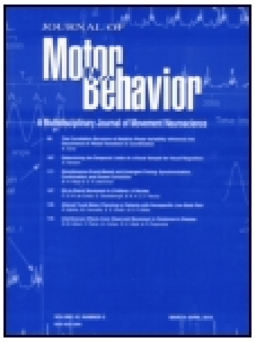

Journal of Motor Behavior

ISSN: 0022-2895 (Print) 1940-1027 (Online) Journal homepage: https://www.tandfonline.com/loi/vjmb20

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To cite this article: E. Paul Zehr (2015) The Potential Transformation of Our Species by Neural Enhancement, Journal of Motor Behavior, 47:1, 73-78, DOI: 10.1080/00222895.2014.916652

To link to this article: https://doi.org/10.1080/00222895.2014.916652

Journal of Motor Behavior, Vol. 47, No. 1, 2015
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COMMENTARY

The Potential Transformation of Our Species by Neural Enhancement

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ABSTRACT. Neural enhancement represents recovery of function that has been lost due to injury or disease pathology. Restoration of functional ability is the objective. For example, a neuroprosthetic to replace a forearm and hand lost to the ravages of war or industrial accident. However, the same basic constructs used for neural enhancement after injury could amplify abilities that are already in the natural normal range. That is, neural enhancement technologies to restore function and improve daily abilities for independent living could be used to improve so-called normal function to ultimate function. Approaching that functional level by use and integration of technology takes us toward the concept of a new species. This new subspecies—*homo sapiens technologicus*—is one that uses technology not just to assist but to change its own inherent biological function. The author uses examples from prosthetics and neuroprosthetics to address the issue of the limitations of constructs on the accepted range of human performance ability and aims to provide a cautionary view toward reflection on where our science may take the entire species.

Keywords: transhumanism, technology, evolution, training, athlete, sport, rehabilitation, superhero, brain-machine interface

> Behold the superman. Man is something to be overcome.
>
> — From *The Will to Power* by Friedrich Nietzsche, 1968

> The changes crept in around the edges, too slow to be noticed, like mold on bread. Fixing serious medical problems first but always moving closer to the simple trials of daily life.
>
> — From the dystopian novel *Amped* by Daniel H. Wilson, 2012

The theme of this special issue is neural enhancement for independent living. I think this represents a critically important translational application of discoveries in neuroscience and allied fields to the improvement of the true lived experience of real people. It is a noble and important theme and objective for any research program. Having said the foregoing, in this personal commentary it is my intention to view more widely some of the broader philosophical issues that neural enhancement raises. This commentary is not intended as an in depth scholarly treatment of neural enhancement in our society. Rather, it is my goal to stimulate some critical thinking about the broader societal implications and applications of our science.

Neural enhancement can be viewed from at least two perspectives. Neural enhancement carries with it the concept of recovery of function that has been lost due to injury or disease pathology. Restoration of functional ability is the objective. For example, a neuroprosthetic to replace a forearm and hand lost to the ravages of war or industrial accident.

From a different perspective, the same basic constructs used for neural enhancement after injury could also be used to amplify abilities that remain intact but are below the desired level. Moving ability from the natural norm or outside the natural range is the objective. Instead, for example, the same approach taken to restore function and improve daily abilities for independent living could be used to improve normal function to superhuman function that may best be considered that of a different species. We might consider this a shift from our subspecies *homo sapiens sapiens* to the emergent *homo sapiens technologicus*—a species that uses and integrates technology and technological devices to enhance its function.

I have rendered the basic concept of the human performance continuum from rehabilitation to super-human (literally meant as above normal) function in the subsequent cartoon diagram. The visual continuum is meant to suggest the seamless transition of applications and concepts from one category to another. At the weakest end of the performance continuum, what we could term the territory of rehabilitation and restoration, most would probably agree that anything that could help return functional abilities after they have been lost to injury is completely acceptable to implement.

What about going from a person's inherent level of ability to some higher or stronger ability level? Silvia Camporesi has nicely phrased this issue as the difference between therapeutic application (far left in Figure 1) versus enhancement (far right in Figure 1; Camporesi, 2008). This is essentially asking what if you could change the overall way your body worked even though it works well now? We would all accept that prosthetics can restore function and

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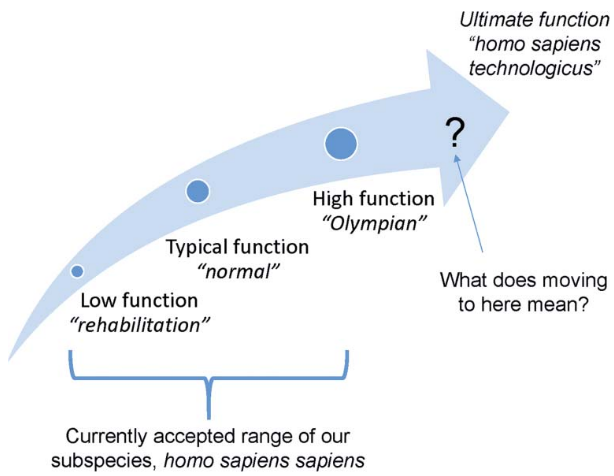

FIGURE 1. A continuum of human performance abilities.

most in society are probably happy with this. But should neuroprosthetics be used to provide enhanced ability?

The focus of this commentary is to briefly examine the societal implications of amplifying human performance abilities by the use of technology. My thesis here has two prongs. First, we must continue to move steadily forward with our efforts to improve the human condition. In so doing, though, the second prong of my argument is that we need to at least have an eye to the future and how our work will be applied not by us nor for the ends we intended, but for any end that can be considered. Part and parcel of this evaluation is a consideration of the way such advances will be viewed, accepted, embraced, or rejected by society. Some of the discussion below has also been addressed in a different light in my speculative nonfiction book *Inventing Iron Man—The Possibility of a Human Machine* (Zehr, 2011).

Clearly technology can be used to amplify human ability. Considering a performance continuum for human ability such as presented in Figure 1 means we have some concept of the range of human ability. Probably for the purposes here the main issue is not the range of human ability, but rather the range of acceptable human ability.

The question is, at what point does the amplification take us beyond the accepted range of natural human ability? Do we actually have an adequate definition for what is the accepted range of normal human ability? In addressing this thesis I explore the issues of (a) the boundaries around which our societal understanding of what is acceptable normal function and (b) the neuroethics of neural enhancement.

Test Case—Do Oscar Pistorius's Prosthetic Blades Restore or Enhance Human Ability?

The issue of enhancement has been tested in the sports arena around the debate about what technology might give an unfair performance enhancement. The most high profile example of which is that of South African sprinter Oscar Pistorius. When he was a competitive sprinter Pistorius was known as the fastest man on no legs since he is a double below knee amputee (Zehr, 2011).

Pistorius was born with fibular hemimelia (or longitudinal fibular deficiency) meaning he did not have fibulas in his legs. Based on this, the chances of Pistorius being able to stand and walk were considered very low. Accordingly, his parents took the decision when he was about 11 months old to allow surgical amputation of his lower legs.

The functional implication of this bilateral double leg amputation was to allow Oscar the use of appropriate prosthetics that could carry his weight during walking and running. For running he used prosthetic legs called blades, so named because the physical shape of the carbon fiber prosthetic looks like a blade. The prosthetics were produced by Ossur and the model was the Ossur Flex-Foot Cheetah (Curran & Hirons, 2012).

Eventually he became the most accomplished and dominant double-amputee sprinter the world has ever seen. The flex-foot part of the prosthetic has caused controversy, though, because that it has been implicated with facilitating his running stride. This is also coupled with the fact that the prosthetic blades are lighter than an intact human lower leg would be.

The sum combination of the prosthetic limbs and superb sprinting biomechanics created considerable controversy when Oscar competed in an International Association of Athletics Federations (IAAF) event held in Rome in 2007. Some observers suggested that Oscar Pistorius could actually run too fast and that his special carbon fiber prosthetic legs actually gave him an advantage over able-bodied runners (Marcellini et al., 2012).

In 2007 the IAAF introduced Rule #144.2, which prohibits "any technical device incorporating springs... that provides the user with an advantage over another athlete not using such a device" (http://www.iaaf.org/about-iaaf/documents/rules-regulations). This prohibition included the blades that Oscar Pistorius used and ended his quest for competing in the 2008 Olympics. However, the Court of Arbitration for Sport based in Lausanne, Switzerland, reversed this IAAF decision in May of 2008. This decision was based on the argument that the IAAF failed to prove that the carbon fiber prosthetic blades provided an unfair advantage (Camporesi, 2008).

Scientific analysis seems to show that the carbon fiber blades significantly enhance performance by improving running efficiency (Weyand, Bundle, Kram, et al., 2009; Weyand, Bundle, McGowan, et al., 2009). Since the blades are actually much lighter than the lower legs they replaced, they can be moved about 15% faster than in the highest performance of sprinters with intact legs (including Olympic gold medalist Usain Bolt of Jamaica). The blades also required 20% less force than was needed to achieve similar running speeds. Using the blades meant that the prosthetic legs only needed about one half of the muscle force needed for sprinting at the same speeds as intact limbs.

Based on legal challenges, the IAAF recanted its ban on use of the blades and the most recent turn in this tale came at the London Games in 2012. In the summer of 2011, Pistorius ran a personal best of 45.07 s in the 400 m, thus satisfying the A standard 45.25 s. This result got him on the South African team for the 2011 IAAF World Championships in Daegu, Korea, where he ran a 45.39 in one of the heats. He did not make it to the final, though, where that same mark would have officially qualified him for the Olympics.

In July of 2012 Pistorius was selected to compete for South Africa in the 400 m and 400 m relay at the London Summer Games. In so doing, Oscar Pistorius became the first amputee runner to compete at the Olympic Games. Although the South African relay team finished next to last in the final, the achievement of Pistorius in making it to and running competitively in the Olympic Games was recognized with Oscar Pistorius serving as closing ceremonies flag bearer for his country (Johnson, 2012).

These amazing achievements again raise the question of whether or not the blades actually did provide a performance enhancement. That is, something that went beyond restoring function to a normal level. Could someone with something that should be an obvious physical barrier to sprinting—no lower legs—actually exceed able-bodied runners by using special equipment?

Brendan Burkett, professor biomechanics at the University of the Sunshine Coast in Australia has raised many very interesting dilemmas when trying to work out the issue of technology in worldwide sports competitions like the Olympic and Paralympic games (Burkett, 2010). If technology can amplify human performance and play an important role in outcomes, what about the problem of equal access to all competitors? Burkett pointed to the rather stunning fact that the Champion of the Marathon at the 1960 Rome Olympics, Abebe Bikila of Ethiopia, actually ran the entire race barefoot. What would his time have been like with access to such technological advances as running shoes? Odds are much better than what he did produce.

In simplest terms, the example of Oscar Pistorius and the use of prosthetic limbs to enhance performance, does raise the rather surreal idea that a present barrier to performance could in fact become the basis for a performance enhancement. We can also consider extending this argument to an extreme example of a talented runner with normal legs who wants to pursue surgical procedures to remove his lower legs so s/he can be fitted with a performance-enhancing prosthetic. What do we as a society say then?

I think the major point to take away from this part of the discussion is that amplifying or enhancing human ability carries with it some ethical and societal implications. This is obviously the case for even more conventional applications in the form of mechanical prostheses like that found in Pistorius' situation. This kind of scenario needs thinking about as we continue to move toward more technologically complex and integrated prosthetics such as brain machine interface or implanted stimulators.

The Untested Case—Neural Enhancement Beyond the Natural Functional Level in Intact, Uninjured Humans

It seems fairly clear that even conventional more mechanically driven technology that was originally designed for restoration of function could be applied to actually enhance performance beyond the range of natural performance. Where is the line between what are acceptable human abilities and what are not? And what happens to that line if we use technology to change the human inside as well as out?

The concept that direct action in the nervous system could be had by electrically stimulating the brain has been with us for a very long time but was clearly established by Fritsch and Hitzig in 1864 (see for review Mussa-Ivaldi & Miller, 2003; Schwalb & Hamani, 2008). Until recently applications of brain stimulation have been largely in the realm of neuroscience research and some clinical diagnostic applications.

Now, though, take for example the current interest in repetitive transcranial magnetic stimulation (rTMS). A quick search on PubMed (January 24, 2014) revealed that rTMS is now seeing applications in: chronic pain syndromes, depression, Parkinson's disease, personality disorder, posttraumatic stress disorder, stroke, bipolar disorder, and, enhancing motor learning. Many of the foregoing are clinical examples that would be in the restoration range as outlined in Figure 1.

Yet it is not a big step toward shifting applications to, for example, enhancing attention and simply improving performance in those who already operate in the natural range shown in Figure 1. Indeed, Clark and Parasuraman (2014) in an editorial on enhancing brain function explicitly state that TMS and related brain stimulation methodologies "can be used to improve attention, perception, memory and other forms of cognition in healthy individuals" (p. 889). Nelson, McKinley, Golob, Warm, and Parasuraman (2014) also showed recently that transcranial direct current stimulation could be used to enhance vigilance in neurologically unimpaired participants.

At this stage we are now asking questions about transhumanism. Is it acceptable in our society for someone to seek a performance advantage by replacing healthy parts of their bodies or enhance brain function with technological constructs? Camporesi (2008) raised a related question: What are the ethics of enhancement using assistive device technology (as could be possible with many current neuroprosthetics) or genetic intervention (as we soon will be able to do)?

Even a decade ago these questions had relevance, but given the pace of advances, they are now critical. They are all the more timely, given that the parts of human function that we are able to modify and restore or enhance continues to expand rapidly (Stieglitz, 2007). The diagram in Figure 2 (inspired by that of Stieglitz), illustrates some head to toe examples of research or commercially available technological devices that can be implanted or worn by humans now.

At initial development, most technologies in these applications were described in terms of restoration and rehabilitation. Some, such as the Google Glass, were initially launched as enhancement or entertainment tools, which are now being viewed with an eye to medical applications (Glauser, 2013). Regardless, many if not all of these could be used as functional enhancements that take us beyond the accepted range indicated at the far right of the performance continuum in Figure 1.

Of course it becomes much more difficult to evaluate what is the range of normal or natural human ability when technology enters the fray. Merging biology, modern technology, and neuroengineering to produce bionics blurs things considerably. *Cybernetics* is another term that has been used and more directly suggests a level of control systems involved in combining artificial intelligence and machine-biological interfaces.

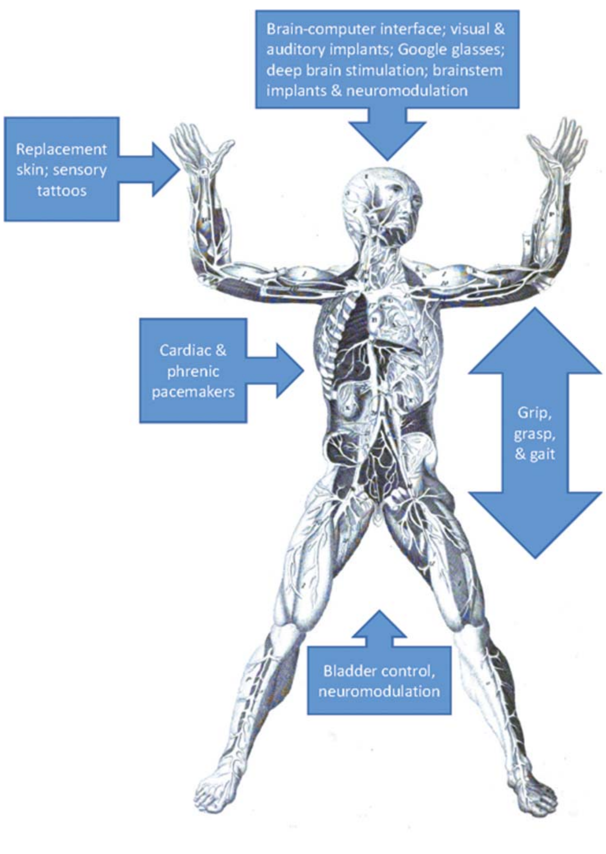

FIGURE 2. Neural enhancement technologies for rehabilitation that could also be used to exceed the range of typical human functional ability. Inspired by Stieglitz (2007).

From cybernetics it is a very short jump to the term "cyborg". All of these jumps, of course, take us further and further away from the "human" range of ability. They do, though, provide a frame of reference for what society has come to accept. Cyborgs can be seen in many and sundry pop-culture references. This concept figures prominently in the BBC Television's *Doctor Who*. *Doctor Who*—the longest running science fiction show in TV history, according to the Guinness Book of World records—in the form of "Cybermen". The Cybermen—and recently cyberwomen—are discussed in entertaining detail along with everything else in the Doctor Who universe by Paul Parsons in *The Science of Doctor Who* (Parsons, 2010).

The cybermen and cyberwomen of Doctor Who represent the extremes of biological and machine connection. They have a significant biological base, even including an artificial nervous system, surrounded by an iron robotic exoskeleton. The rise of the cybermen is described as a parallel humanoid species that began implanting technology and artificial parts into their bodies until they one day crossed from humanoid species to cyborgs.

These are admittedly examples culled from popular culture and clearly we are not that far down that road with current approaches in neurorehabilitation. Just as clearly, though, we are taking some speculative steps in that direction. The rate of those steps is also increasing rapidly. In 2013, the London Science Museum unveiled robotic exoskeleton (REX), a completely manufactured cyborg consisting of organs and organ systems from laboratories and companies around the world, including artificial eye and kidney (University of California, Los Angeles, CA), ear (Macquarie University, Sydney, Australia), trachea (Royal Free Hospital, London, England), heart (SynCardia, Tucson, AZ), spleen (Yale University, New Haven, CT), pancreas (De Montfort University, Leicester, England), hand and arm (Touch Bionics, Livingston, Scotland; Johns Hopkins University, Baltimore, MD), blood (Sheffield University, Sheffield, England), and foot and ankle (MIT, Cambridge, MA). REX stands with the aid of a bilateral leg robotic exoskeleton (Payne, 2013).

In truth, I remain stunned by how rapidly research applications are progressing. In *Inventing Iron Man* (Zehr, 2011) I made the argument that for the exoskeleton of Marvel's character to truly function as we see it in movies and in graphic novels (Mangels, 2008), it would have to be a neuroprosthetic controlled by neural commands from the spinal cord and brain. That is, the ultimate brain-machine interface connecting a human to a powered robotic exoskeleton.

In framing a technological superhero in this way, I made a number of, what I believed at the time to be speculative and prescient predictions. One was that to truly function seamlessly, a human exoskeleton like that of Iron Man needed to have sensory feedback. This would come from the suit like a kind of synthetic sensory skin and would feed back into the sensory cortices via the brain machine implant. The second was that connecting a neurological implant in the brain to control an exoskeletal system means a possibility for bidirectional information flow. Namely, that if the controllers for the exoskeleton were hacked (as happens routinely in comic books and science fiction movies!) someone would be able to control the human user through the same interface.

These were predictions I thought would take some years to achieve, but I was unable to bask in the glory of these predictions for very long. In 2011 before *Inventing Iron Man* was released by Johns Hopkins University Press, O'Doherty et al. (2011) published an article in *Nature* demonstrating enhanced learning of brain machine interface control in the mouse when sensory stimulation was included in the design.

This was followed by the same group demonstrating real-time sharing of behaviourally relevant sensory information between the brains of two rats located in separate geographical regions (Natal, Brazil; Durham, NC; Pais-Vieira, Lebedev, Kunicki, Wang, & Nicolelis, 2013). While this design did not actually use the hack of remote controlling one rat from a distance, this was proof principle of exactly this concept.

Of course a major challenge for neuroprosthetics is also the power supply issue for any controllers, devices, or effectors that might be implanted or worn. Energy harvesting may be a solution. Just early in 2014, the laboratory of John Rogers (Dagdeviren et al., 2014) provided a proof of principle demonstration of "a complete, flexible, and integrated system that is capable of harvesting and storing energy from the natural contractile and relaxation motions of the heart, lung, and diaphragm at levels that meet requirements for practical applications" (p. 1927), which could include neural stimulation. When it comes to neural enhancement technology, the future truly is now.

Welcome Superhero or a Bridge Too Far?

Where does all of the foregoing leave us? I must admit that in all reality we are left with more questions than answers. The critical piece, though, is that we continue to ask these questions and strive for answers while we continue to advance the field of neurorehabilitation.

To return to the quote from the novel *Amped* (Wilson, 2012) that led off this essay, the slow invasion of implants and assistive devices can occur almost without notice. Wilson's science fiction novel takes place in a dystopian future where neural implants (most notably something called the neural-autofocus that is used to sharpen concentration and intelligence) become widely available. In the beginning, these devices were introduced for use in those with cognitive disabilities, mental challenges, or health risks (e.g., to control epilepsy), but they eventually see widespread application throughout the population. Subsequently a two-tiered class of humans emerges—those who are amped and those who are not. Many ethical and moral issues are addressed in this engaging science fiction novel. Shortly many of the technologies may no longer be fictional and many of the ethical issues will require solutions.

As we move forward in the fields of neuroprosthetics and neural enhancement that truly are still in their infancy, I suggest it is critical that we allocate some of our attention and some mindfulness on what the future may hold. Through our use of technology we are potentially at the threshold of scientific advances that could fundamentally change who we are as a species. Will our species of *homo sapiens* (literally wise men) use our technology to transform our species into technical man—*homo sapiens technologicus*—a new subspecies deliberately modified and tailored by its own hand?

Currently our technologies are still relatively nascent and typically applied in the case of neurorestoration. As the field matures, however, to what ends will these technologies be applied, and using what means? I suggest that presently we are on the path toward the superman of Nietzsche by overcoming the limits of our species through application and internalization of our swiftly increasing technological ability.

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Received January 30, 2014
Revised April 11, 2014
Accepted April 15, 2014