Homuncular Flexibility: The Human Ability to Inhabit Nonhuman Avatars

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Abstract

This essay seeks to explicate an unorthodox idea that spans psychology, neuroscience, psychology, philosophy, and computer science called *homuncular flexibility* (*HF*). HF posits that the homunculus—the part of the cortex that maps movement and sensing of body parts—is capable of adapting to novel bodies, in particular bodies that have extra appendages or appendages capable of atypical movements. Evidence demonstrates neural plasticity in nature; for example, amputees experience cortical shifting such that their face receives extra attention in the brain after a limb is amputated. However, experiments such as the rubber hand illusion, in which people respond to rubber hands placed near their arms as if they were their actual hands, demonstrated that a person's sense of their body can be adjusted to include external objects. The recent advent of virtual reality technology, which can track physical human motions and display them on avatars, allows for the wholly new human experience of inhabiting distinctly nonhuman bodies. HF is a paradigm in which physical motions are transformed by remapping degrees of freedom from tracked movements onto an avatar. For example, if a human being were to inhabit an avatar of a lobster, controlling two of the eight lobster arms would be simply be a function of tracking the two physical arms and directly mapping those movements onto the avatar's first two arms. However, in order to control the remaining six arms, degrees of freedom that are orthogonal to the movements of the first two arms need to be measured and remapped. In this essay, we discuss advancements in neuroscience, psychology, and computer science that relate to HF. We review some preliminary studies that demonstrate how humans accommodate novel bodies. Finally, we discuss theoretical implications and practical applications relating to HF.

HISTORY OF HOMUNCULAR FLEXIBILITY

Accounts of the history of experimentation are usually paced by examples of phenomenon coming to light because of improved instrumentation. homuncular flexibility (HF) is a rare example of the opposite; it was first noticed because of poor instrumentation.

The 1980s saw the first attempts to implement networked immersive virtual worlds (deemed "virtual reality") at VPL Research. To be networked,

users would experience being present in a shared virtual setting and would be able to see representations of each other. Thus, it was necessary to create three-dimensional avatars of each user. One of the strengths of the early development system for virtual reality at VPL Research was that it supported extremely rapid prototyping, with revisions appearing instantly while a subject was "inside" a virtual world experiment. The calibration of early full-body avatars presented a challenge; it was difficult to design a suit so that sensors would remain in precisely the same locations on the user's body with extended use. In the context of rapid experimentation with mappings and heuristics, it came to pass that nonrealistic, whole-body avatars were occasionally activated. These would usually result in a complete breakdown of usability. As an example, if an avatar's head were made to jut out of the side of the hip, the world would appear rotated awkwardly to the user, who would immediately become disoriented, unable to perform any task. In the course of exploring avatar designs, researchers occasionally came upon an unusual avatar design that preserved usability despite being nonrealistic or even bizarre.

The first one occurred during the process of creating an immersive city and harbor planning tool, a collaboration between Jaron Lanier at VPL Research and Tom Furness and others at the HITLab of the University of Washington. One of the scientists was inhabiting an avatar—a worker at the docks in Seattle—when his arm was made very large, perhaps the size of a very large crane. This most likely occurred because a designer entered extra zeros in a scale factor in the software that measured movement. What was remarkable was that the scientist was able to pick up vehicles and other objects in a large scene at great distance with a highly distorted arm, and was able to do so with accuracy and no apparent loss of usability.

This unexpected observation, and others similar to it, motivated an informal study of "weird avatars that were still usable." A number of increasingly strange, but usable, nonhuman avatars were created and tested between approximately 1989 and 1991. Most of these resembled mammals, in terms of overall structure and inventory of limbs.

A number of principles emerged via informal pilot testing. For example, it appeared that the relative scaling of parts of the body was surprisingly plastic. The attachment points of limbs could be changed so long as the angle of attachment did not change too much. However, the ultimate strange avatars departed from the mammalian plan entirely. Most of these did not preserve usability. However, there was one that bears mention. One colleague, Ann Lasko, had seen a postcard of people in lobster suits at a festival, and created a lobster avatar and set about programming a body map for it. As the lobster body includes more limbs than a person, there were not enough parameters measured by the body suit to drive the lobster avatar in a one-to-one

map. Therefore, the scientist mapped the degrees of freedom of the body suit to the greater number of degrees of freedom of the lobster. The initial mappings were not usable, but over time, as the algorithms to control the extra limbs evolved, some mappings emerged that succeeded. Over time, and with practice, humans were able to slowly learn to control the lobster. The biologist Jim Bower, when visiting Lanier's lab during this period, commented that the range of usable nonhuman avatars might be related to the phylogenetic tree. The human brain might be expected to find body plans that had occurred in the history of its own descent to be more usable than other body plans, though of course this would not include the lobster. Nonetheless, the intriguing question remains of what makes certain nonhuman avatars usable while others are not.

In this essay, we will first give a rough description of the brain structures that might support flexibility of virtual embodiment. Then, we review some landmark findings related to brain plasticity that provide foundations for the current work on remapping physical bodies onto avatar bodies. Next, we describe recent work in virtual reality that tests the ability of people to accommodate various avatar bodies. Finally, we suggest two frameworks for organizing this emerging area of research—one based on the overall *function* of the transformation—for example, restoring function compared to inventing function, and the other based on the *mode* of the transformation.

THE HOMUNCULUS AND EXPERIMENTS IN NEURAL PLASTICITY

The "homunculus" in the term *HF* refers to motor and somatosensory representations of the human body in the brain. Both the primary motor cortex and the primary somatosensory cortex contain areas where the innervation arising from different parts of the body roughly maps to corresponding cortical regions. These areas form Penfield's "homunculus" (Penfield & Boldrey, 1937). As with many brain structures, the left side of the body is represented in the right cerebral hemisphere, and vice versa. The primary motor cortex, which relates to muscle movement, is located on the frontal side of the central gyrus, whereas the primary sensory cortex, which is involved in the perceptions of touch sensation, opposes it. A schematic approximating the relationships of these two structures is shown in Figure 1.

Areas of the body with greater innervation are represented by more space in the primary motor cortex than body parts with less innervation. Thus, the hands, which have complex movements/muscular innervations, take up more space than the leg. This mapping is not currently considered to be one-to-one; it has been proposed that rather than specific cortical regions mapping to specific muscles, the motor cortex controls the motions made by these body regions (Barinaga, 1995). However, it does provide for a general

Cross-section of right hemisphere
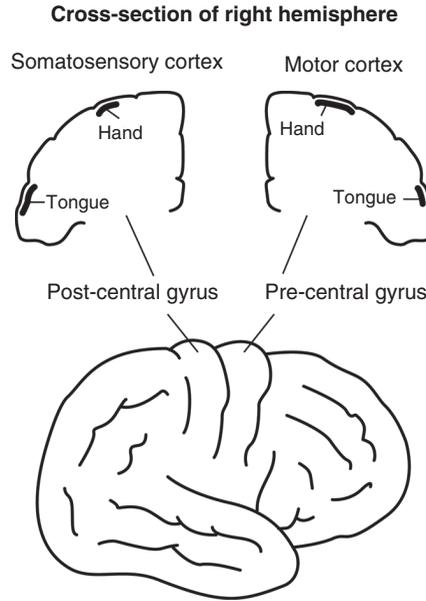
Figure 1   Homunculi of the somatosensory and motor cortices, showing the differences in size mapping for the hand and tongue in the somatosensory and motor cortices, reflecting their comparative differences in innervation.

relationship between brain regions and the movements of different regions of the body. The primary somatosensory cortex is similarly arranged, such that parts of the body with greater sensitivity, such as the lips, fingers, and thumb, take up more space than, for example, the back. In contrast to the motor cortex, the hands are less dominant in the sensory cortex, whereas the sensitive (but immobile) teeth and gums are well present here but not in the motor cortex.

The mappings of the somatosensory and motor cortex may be altered by injury. For example, in the case of an amputated arm, cortical mapping may shift such that areas that previously innervated the hand may shift to another part of the body (Roricht, Meyer, Niehaus, & Brandt, 1999). This cortical plasticity is hypothesized to be one source of phantom limb pain.

Phantom limb pain is the phenomenon in which an amputee continues to have sensation, sometimes very painful, perceived as originating in the absent limb long after the trauma has healed. This persistent pain has been proposed to result from cortical remapping. In 1996, Ramachandran and Rogers-Ramachandran proposed that altering the visual input that patients received could help in remapping the motor cortex and thus alleviate phantom limb pain. To do this, they designed a box with a mirror in the midline. When patients placed their uninjured limb in such a box, it created

the illusion of two normally moving limbs. This appeared to relieve some patients' pain, perhaps because the pathological cortical map was restored by the visual input of a plausible limb in the location of the amputated limb. Similarly, Lotze, Flor, Grodd, Larbig, and Birbaumer (2001) have proposed that the use of a myoelectric prosthesis providing similar visual feedback may prevent cortical reorganization and the accompanying phantom limb pain. Therapies building on mirror visual therapy have also been used to treat complex regional pain syndrome (CRPS), a condition with some similarities to phantom limb pain (Sato *et al.*, 2010).

Visual feedback combined with somatosensory input has also been proposed to change a person's understanding of his or her body. Stroking a prosthesis as a substitute for a missing limb has been proposed as a therapy for phantom limb pain (Ramachandran & Rogers-Ramachandran, 1996) and CRPS (Schmalzl, Ragnö, & Ehrsson, 2013). Creating the illusion of touch has also been suggested for pain syndromes in the face that would not respond well to movement-based mirror therapies (Ramachandran & Altschuler, 2009; Won & Collins, 2012). These therapies build upon a phenomenon of body schema transfer often linked to phantom limb pain, known as the *rubber hand illusion* (Botvinick & Cohen, 1998). In this illusion, a participant's hand is placed underneath a cloth or a table on which a rubber arm is laid. The participant's real hand and the rubber hand are then stroked at the same time with a soft brush. Gradually, the patient feels a sense of increasing ownership toward the rubber hand, and he or she will flinch if the rubber hand is suddenly hit with a mallet. IJsselsteijn, de Kort, and Haans (2006) replicated the illusion in the physical world, in virtual reality, and in mixed reality, finding effects across conditions, although the illusion was strongest in the unmediated condition. A similar experiment using touch on an elongated rubber arm used magnetoencephalography to demonstrate changes in the somatosensory cortex. In this experiment, the cortical representations of the little finger and thumb moved closer together during the stroking portion of the illusion compared to both the control and the resting states. In addition, subjective report of the feeling of an elongated arm correlated significantly with a change in the cortical distances (Schaefer, Flor, Heinze, & Rotte, 2007).

These cases of remapping hint at how malleable an individual's sense of their body may be. In order to consider how humans can identify with entirely new bodies, we will now discuss more radical examples of avatar alteration. We propose that given the proper visual/sensory or visual/motor input, users can learn to control, and possibly identify with, bodies radically different than their own. In the following section, we will discuss how virtual reality leverages its unique abilities to track and render motion to create the illusion of embodying a new persona.

RELATED RESEARCH ON VIRTUAL AVATARS

In this section, we describe the technology required to create avatars, representation of people in virtual reality. We then discuss research that examines the relationship between oneself and one's avatar, in particular, research that begins to test the process and effect of HF.

Virtual reality is implemented as a function of three distinct processes: tracking, rendering, and display. Consider the first commercially successful video game called *Pong*. A player had a virtual experience that featured a table-tennis like game, and controlled a virtual racquet. In order to do so, his hand was "*tracked*"—a device measured the rotation of the players' hand via a mechanical device that rolled from side to side. Then, the screen was *rendered* with each new movement—if the roller detected the hand moved to the left, then the racquet was redrawn in a digital scene to be a few pixels over. Finally, the newly rendered scene was *displayed* via sights (an array of pixels changed colors to show the scene) and sounds (speakers produced sounds to accompany the action on the screen). This process—tracks the person's movements, changes a digital scene accordingly, and updates the senses to receive this new scene—repeats itself at a high frequency such that the transitions are seamless.

In virtual reality, people are represented by *avatars*, digital representations that are controlled by the actions of a human being in real time (for an explication of the concept, see Bailenson & Blascovich, 2004). A number of scholars have examined the process and the implications of occupying bodies different from the physical self. In an early explication of this concept, Frank Biocca (1997) coins a term known as *self presence*, the degree to which one perceives one's avatar as his or her actual self. He provided a framework discussing the mismatch between one's avatar and one's physical self, and posited the psychological effects these mismatches might have on those who utilize avatars. A recent chapter by Ratan (2012) provides a thorough description of this concept. The idea that the self can be present in a mediated body is key to the concept of HF in virtual reality.

About a decade after Biocca's first discussion of this notion, Nick Yee and colleagues began a research program that tested this notion (see Blascovich & Bailenson, 2011, Chapter 7, for a review of these studies). The so-called Proteus effect (Yee & Bailenson, 2007) states that "an individual's behavior conforms to their digital self-representation independent of how others perceive them" (p. 271). In these cases, a person can be lead to identify with an avatar simply by seeing the mirror image of that avatar move in conjunction with the users own movements. Given the familiarity of seeing one's own movements reflected in a mirror, this combination of mirror and motor input appears to be sufficient to create an identification with the avatar body, even

when the avatar's body is different than one's physical body—for example, a different race or gender. This effect is lasting enough that participant's behavior is found to conform to the stereotypes of the avatar, even after the user exits virtual reality, and is typically measured by behavioral dependent variables. For example, those with taller avatars behave more confidently than those with shorter avatars (Yee & Bailenson, 2007), college students who use senior citizen avatars are more likely to put money in a savings account than those wear age appropriate ones (Hershfield *et al.*, 2011), men who embody female avatars behave in a more nurturing manner than men who embody male avatars (Yee, Ducheneaut, Yao, & Nelson, 2011), and people who see their own avatars exercising are more likely to exercise than those who do not (Fox & Bailenson, 2009). In sum, the mismatch between the physical self and the virtual self, proposed initially by Biocca, has both psychological and behavioral implications.

At around the same time that Yee and colleagues were studying the *implications* of spending time in bodies different than one's physical self, Ehrsson (2007) and colleagues began to study the *process* of transferring one's sense of self to virtual bodies. By utilizing techniques of synchronous touch, that is, when a user feels tactile feedback on their body that corresponds to the same visual feedback on an external body that is typically displayed via video, these scholars shed light on the neural mechanisms behind the process of self presence. Slater and colleagues have thoroughly extended this "body transfer" paradigm to test the process of inhabiting various avatars that are fundamentally nonhuman. For example, in one study, Slater, Spanlang, Sanchez-Vives, and Blanke (2010) compared the effects of simultaneous touch, first person perspective, and coordinated head movements in generating a feeling of transfer from male participants to a female avatar in virtual reality, and a corresponding physiological response when the body of that avatar was suddenly attacked. Participants also reported a subjective feeling of body transfer despite the fact that the gender was swapped. In another study (Kilteni, Normand, Sanchez-Vives, & Slater, 2012), participants were led to identify with a body with one arm rendered as much longer than a normal human arm. Identification was created using a combination of somatosensory and visual input, and identification was confirmed using physiological reaction measures, and the extent to which participants flinched in real life, when the "long" arm was threatened. This confirms the finding described earlier by Schaefer *et al.* (2007) who demonstrated shifts in the somatosensory cortex when the rubber hand illusion was duplicated using an unusually long hand.

EMPIRICAL INVESTIGATIONS OF HOMUNCULAR FLEXIBILITY

More recent research is providing direct tests of the ability of people to *control* bodies with expanded function, that is, ones that allow people to implement motor skills that humans have never been able to attempt previously. For example, Steptoe, Steed, and Slater (2013) demonstrated that people were able to accommodate avatars that had tails that were controlled by hip movements, and felt distressed when those tails were threatened.

The three authors of this essay have also collaborated on empirical research examining how humans adapt to controlling avatars with different limb structures (Won, Lee, Bailenson, & Lanier, in press). In two studies, we manipulated one's ability to control novel bodies, and examined how experimental participants adapted to the new bodies.

The first study involved switching the tracking data of virtual arms and legs, such that virtual arms adapted features typically associated with physical legs, and vice versa. There were three conditions: normal, switched source, and switched range. Figure 2 demonstrates the normal condition. In this condition, when a participant arm moves her physical arms and legs, they are tracked and the avatar's limbs move accordingly, with similar ranges.

The switched source condition is depicted in Figure 3. In this condition, when the participant moves her physical legs, her avatar moves its virtual arms. Similarly, when the participant moves her physical arms, her avatar moves its virtual legs.
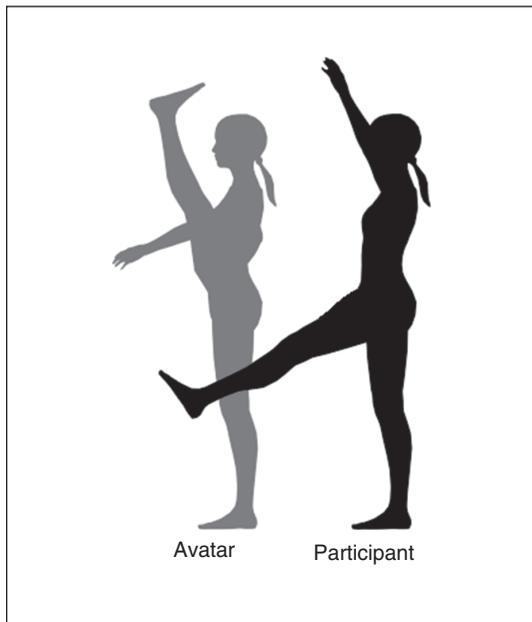
Figure 4 demonstrates the switched range condition. Here, the participant's arms and legs move the appropriate avatar limbs, but the range of the avatar's limb movement is either expanded (in the case of the virtual legs, which now have the range of real-life arms) or contracted (in the case of the virtual arms, which now have the range of real-life legs, and do not rise

Figure 2   Normal tracking showing the participant's tracked movements (black figure) and the resulting rendering of the avatar (gray figure).
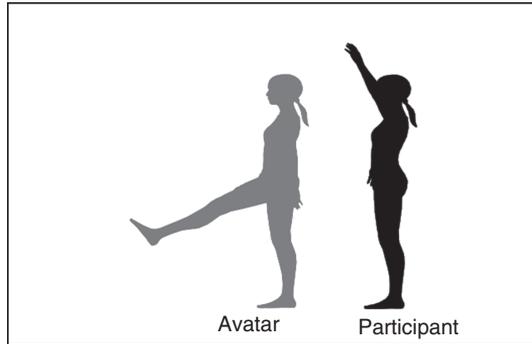
Figure 3   The switched source condition showing the participant's tracked movements (black figure) and the resulting rendering of the avatar (gray figure).

Figure 4   The switched range condition showing the participant's tracked movements (black figure) and the resulting rendering of the avatar (gray figure).

above the shoulder). In other words, the avatar gets to move its legs with more range than humans do, and its arms with less range than humans do.

In our study, the participants were tasked with popping balloons for about 10 min. The balloons appeared in random spots in $X y Z$ space and were reachable by either the virtual hands or feet. We were able to track the number of balloons they could pop with specific limbs, as well as the overall

movement of the four limbs. Participants used their physical arms to pop balloons in the normal condition, as their arms offered a greater range to reach the randomly appearing balloons and humans are also more accustomed to using their arms to manipulate the physical environment. In the switched source condition, they used their physical legs (which were then powering the avatar's arms) more often than in the normal condition. However, this did not establish whether or not participants were motivated by the greater range reached by the avatar's arms, or whether participants simply preferred the naturalness of seeing one's virtual arms perform the task in the virtual environment. Thus, we implemented the switched range condition, which demonstrated that participants would use their physical legs more than their physical arms when offered the utility of a leg that could sweep across the range of the balloon space. In addition to the performance data, anecdotally, subjects would at first be disoriented but would only take a few minutes to accommodate to the new body structures.

In the second, within-subjects study, participants were provided with a third arm, which emanated from the middle of their chests, and extended about 1.3 m forward. The participants could rotate their left wrist to control the x position of their third arm, and could rotate their right wrist to control the y position of their third arm. The wrist rotations were orthogonal to the position of the left and right arms, so the control scheme did not interfere with the ability of the natural arms to perform a task. In this study, participants had to touch cubes floating in space. Some of the cubes were within arm's length of the participants, whereas others were approximately. 5 m further away in front of them. In the third arm condition, the close cubes were reachable by the natural arms, and the far cubes were reachable by the third arm without walking. In the normal condition, participants had to step forward to touch the most distant cube with one of their two hands. A trial was defined by completing a task of hitting two close cubes and one far cube. Participants took <5 min, on average, to master using the third arm. After 5 min, the scores in the third arm condition were routinely higher than those in the normal condition (Figure 5).

AN ORGANIZING FRAMEWORK

There have been a number of attempts by scholars to provide an overall framework for thinking about this research on embodiment as it relates to neural plasticity. For example, Clark (2007) provides a novel framework to think about augmenting the self as it relates to tool use and neural plasticity. In their 2012 paper, Haans and IJsselsteijn (2012) discuss how tools and other artifacts may be incorporated into different levels of embodiment, and what this implies for the experience of telepresence, including in more novel avatar
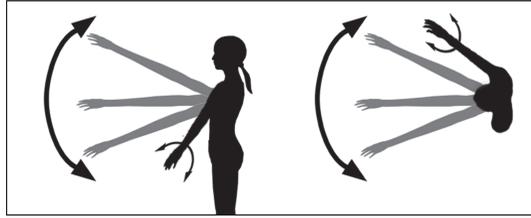
Figure 5 The schematic shows the method of controlling the "third limb" (shown in gray extending out of the participant's chest). Rotating the right wrist moved the participant's third limb up and down, whereas rotating the right wrist moved the avatar's third limb from side to side. Thus, rotating both arms allowed the participant to control the third limb while also hitting targets with the left and right arms.

bodies. In this essay, we do not propose an overarching theory to explain the process, but rather suggest an organizing framework to help provide a common language.

First, one can consider the changes in body schema from a functional standpoint. The first function is *restoring* the body. For example, the research on how the homunculus adjusts to the presence of a prosthetic limb would fit this category. The second is *replacing* the body with one that has equal human function. For example, scholars who study the process and implications of "gender-bending," that is, avatar gender that does not match physical gender, fit this parameter. The third is *reinventing* [term adapted from Clark (2007)] the body, by providing bodies, or at least body parts, which are decidedly nonhuman, but yet can be controlled by a human user, for example, having a third arm.

However, one can also sort these experiences by the mode in which the user's sense of embodiment is transformed. Changes within a single channel of interaction, such as adding extra limbs that are controlled by different degrees of freedom from the participant's physical body, would be considered a type of *ipsimodal remapping*. Another type of transformation moves between different modes. For example, if spatial information that would normally be perceived visually is presented audibly, as in aids for the visually impaired, that would be a case of *sensory substitution*. A third type of transformation would remap tracked input that the user may not consciously experiences (such as heart rate or EEG information) into renderings that the user, or another, may easily observe and use. For example, an avatar might change colors to match his or her emotion, or move more quickly when the user is agitated. These would be cases of *para-synthetic expression*.

CONCLUSION

The notion of HF is one that has been percolating for decades, but recent technological advancements are bringing the construct to the forefront of research that spans computer science, neuroscience, psychology, and biology. As research continues to push the boundary on what it means to be human for the purpose of basic science, it is also important to consider the practical implications of this work.

Consider video games in the year 2013. The Microsoft Kinect, the fastest selling consumer electronic product in the US history as determined by Guinness, has completely transformed the notion of tracking. Instead of holding onto a physical device, the Kinect uses the body itself as an input device. In other words, it unobtrusively—that is, the user does not have to wear any special markers or hold any devices—tracks body movements, by emitting infrared light that then hits the user, reflects back to the device, and can figure out the position of various limbs by creating a depth map of the body. Instead of a single joystick to control a video game, the user now has many degrees of freedom to control a virtual experience, for example, hand, arm, leg, and head movements. Of course, researchers studying virtual reality have been tracking body movements for decades (see Blascovich & Bailenson, 2011, Chapter 3, for a review), but for the first time ever, it is possible to do it cheaply and unobtrusively.

One area to apply this work is in the idea of empathy. Research has demonstrated that avatars have a unique ability to allow one to "walk a mile" in someone else's shoes, be allowing them to literally become someone of another race, gender, or social category. Work by Ahn, Le, and Bailenson (2013) placed humans with normal vision in avatars with visual impairments, such that the humans were able to viscerally experience a disability. Compared to control conditions, for example, imagining one had the disability, the avatar experience caused experimental subjects to volunteer more of their own time to help those with disabilities, and their attitude change toward the disabled remained changed a day after the virtual treatment. Similarly, this notion of body transfer should be able to allow people to gain empathy for different species. The plight of an endangered animal will likely feel more personal and salient when a person experiences a day in the life in that animal's body.

Another obvious application of this framework is to increase human function, to literally have eyes on the back of one's head and to be in multiple places at once, via an expanded body. There are many other possibilities for productivity, education, entertainment, and travel. On the other hand, it is critical to keep a skeptical eye on these applications, and to monitor the academic research closely as we build these applications for society at large.

Clifford Nass and colleagues (Ophir, Nass, & Wagner, 2009; Pea *et al.*, 2012) have demonstrated that, while alluring, multitasking—specifically using more than one form of media at once—is robustly counterproductive, and possibly harmful to cognitive function. It remains to be seen if hidden costs from occupying novel bodies with "extra" functions, especially over time, arise.

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ANDREA STEVENSON WON SHORT BIOGRAPHY

Andrea Stevenson Won received her MS in Biomedical Visualization from the University of Illinois at Chicago in 2005. She is a PhD candidate in the Department of Communication at Stanford University. Her research interests

include mediated self-representation and tracking, assessing, and manipulating body movements to affect outcomes. She is a member of the International Communication Association. Contact her at aswon@stanford.edu.

JEREMY N. BAILENSON SHORT BIOGRAPHY

Jeremy N. Bailenson is founding director of Stanford University's Virtual Human Interaction Lab, an associate professor in the Department of Communication at Stanford, and a senior fellow at the Woods Institute for the Environment. He earned a BA cum laude from the University of Michigan in 1994 and a PhD in cognitive psychology from Northwestern University in 1999. After receiving his doctorate, he spent 4 years at the Research Center for Virtual Environments and Behavior at the University of California, Santa Barbara as a post-doctoral fellow and then an assistant research professor.

Bailenson's main area of interest is the phenomenon of digital human representation, especially in the context of immersive virtual reality. He explores the manner in which people are able to represent themselves when the physical constraints of body and veridically rendered behaviors are removed. Furthermore, he designs and studies virtual reality systems that allow physically remote individuals to meet in virtual space, and explores the manner in which these systems change the nature of verbal and nonverbal interactions. In particular, he explores how virtual reality can change the way people think about education, environmental behavior, and health.

His findings have been published in over 90 academic papers in the fields of communication, computer science, education, law, political science, and psychology. His work has been consistently funded by the National Science Foundation for over a decade, and he also receives grants from various Silicon Valley and international corporations. He consults regularly for government agencies including the US Army and Air Force, the Department of Defense, the Department of Energy, the National Research Council, and the National Institute of Health on policy issues surrounding virtual reality.

His book *Infinite Reality*, coauthored with Jim Blascovich, was recently quoted by the Supreme Court outlining the effects of immersive media.

JARON LANIER SHORT BIOGRAPHY

Jaron Lanier is a member of Microsoft Research. He either coined or popularized the term *virtual reality* and in the early 1980s founded VPL Research, the first company to sell VR products. He led the team that developed the first implementations of multi-person virtual worlds using head-mounted displays, for both local and wide area networks, as well as the first "avatars," or representations of users within such systems. While at VPL, he and his colleagues developed the first implementations of virtual reality applications in

surgical simulation, vehicle interior prototyping, virtual sets for television production, and assorted other areas.

Harvard's Kennedy School of Government chose Lanier's book "*Who Owns the Future?*" for 2014s Goldsmith Award. He received a Lifetime Career Award from the IEEE in 2009 for contributions to virtual reality, and was the recipient of CMU's Watson award in 2001. He has received honorary doctorates from the New Jersey Institute of Technology and Franklin and Marshall College. He has also been affiliated with USC, UC Berkeley, NYU, Columbia, UPenn, and Internet2. He has written best-selling books, such as "*You Are Not a Gadget*." He is also a composer of "classical" music (with commissions from the St. Paul Chamber Orchestra and others) and plays a large number of instruments (having performed with Philip Glass, Yoko Ono, George Clinton, Ornette Coleman, and many others.)