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Introduction: the cognitive take on avatar immersion and embodiment

- 1 Present-day virtual reality experiences predominantly make use of user-avatars designed to enhance their immersive potential. The mental processes at work in what Perény (2015) has described as avatar immersion—or “avatar embodiment,” in the sense of being incarnated in a virtual body—are crucial to understating how the appropriation of a digital body plays out. In this paper, avatar immersion is defined as a user’s ability to forget their avatar, viewed as a transparent vehicle for actions and motor sensations. This first concept is usefully supplemented by the notion of avatar embodiment, applicable whenever the mind processes the properties of the virtual body in the same way as those of the physical body (Kiltner *et al.*, 2012). A successful embodiment in a virtual entity hence relies on the subject’s ability to coordinate her cognitive self-representation with the modeled representation of the digitally simulated body at her disposal. These two representations fall in line in the presence of a phenomenon described as the transfer of the individual’s body schema and body image onto the digital representation of the virtual body (Biocca, 1997). This cognitive transfer of mental representations of the body lets the subject identify and accept the virtual body as an integral part of her corporeality, as defined in reference to Amato’s “own body” (2008).
- 2 These phenomena raise the following question: how can the user improve her sense of virtual immersion when inhabiting a virtual body perceived as pertaining to her own?

- 3 The overarching aim of this paper is to explain how users develop a sense of ownership over a digital avatar body. Our approach draws on the theory of embodied cognition (Coste, 2003; Edmiston & Lupyan, 2017; Shapiro, 2012) and on sensorimotor theories of perception (Gibson, 1966, 1979; Havelange *et al.*, 2002). As a first step, the theory of embodied cognition will help us outline the concept of corporeal representation and account for the existence of cognitive functioning in virtual environments. Second, we will lay out the basic principles (1) of cognitive self-representation, examining notions relating to the body and to the body schema from a cognitive standpoint, (2) of body image, and (3) of cognitive self-identity. Third, we will define the avatar as a digitally simulated body, according to a concept of corporeal relation which takes a cognitive standpoint. The differences between the physical body and the digital body will be laid out in connection with this cognitive relation. We will go on to recap how the digital-corporeal sense of ownership develops according to sensorimotor theories of perception, placing particular emphasis on self-avatars, i.e., avatars that take on the physical appearance of the user. Finally, we will examine how the feeling of owning an avatar's body influences our sense of immersion and presence in the virtual environment. This exploration will be illustrated through several diagrams that will help us sum up the advances made by connecting the concepts revisited throughout this investigation into the nature of virtual avatar embodiment.

The theory of embodied cognition: the relationship between cognition, body, and environment

- 4 Embodied cognition is a school of thought based on a wide-ranging multidisciplinary research program that draws from work in psychology, neuroscience, ethology, philosophy, linguistics, robotics, and artificial intelligence. Since the 1960s, in the field of psychology, a certain branch of literature has drawn a distinction between cold, purely functional cognition and so-called hot cognition, which takes into account the affective dimension of cognitive processes (Lepper, 1994). Embodied cognition combines these two aspects by considering the role of the body in cognitive processes, and vice versa (Wilson & Foglia, 2013), hence challenging computationalism's view that the brain, as a biological computer, is the seat of cognition, independent from the body. Closer to embodied cognition is enactivism, which considers that cognition emerges from, or is constituted by, sensorimotor activity. Cognition is generated and specified by sensorimotor processes rooted in interactions between the brain, the body, and the world (Varela *et al.*, 2017). Enactivism holds that perception consists in an active exploration of the environment, which establishes patterns of dependence between our movements, sensory states, and the world. Perceivers need not build and manipulate internal models of the external world. Instead, they need only skillfully exploit sensorimotor dependences that their exploratory activities reveal.

The paradigm of embodied cognition states that: many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent's beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent's cognitive processing. (Shapiro & Spaulding, 2021, p. 1)

- 5 Embodied cognition stresses the importance of the body in cognitive processes. Cognition is a phenomenon that emerges from the body, which receives proprioceptive

and exteroceptive stimuli, or input, from the environment, and plays a central role in the individual's behavioral response, or output. As a result, the corporeal properties of an organism generate different understandings of the environment from one individual to another. The way environmental input and output are processed depends on the constituted nature of the body. Consequently, cognitive processes that relate to how data is taken up and processed, beyond the nervous system and sensory organs, also involves the way the body takes in, and responds to, its environment. The body does not merely contribute to cognitive processes in a causal manner, but also plays a fully constitutive role within the cognitive system.

- 6 In virtual reality (VR), the physical body is doubled by a virtual body. But the three-sided relationship between cognition, body, and environment persists, and appears to impact the cognitive processes of learning and memory in a similar way in the physical world and in the virtual world. Basic cognitive mechanisms, such as attention, perception, planning, recognition, and representation, can then be transferred from the individual to her virtual character. However, for a transfer to be effective, it would seem that behavioral and visual likeness is called for between the avatar's features and those of an individual's cognitive self-representation.

The complex process of cognitive self-representation

- 7 Because someone who sees themselves as moving through a virtual world does not merely see themselves as piloting a virtual character, it matters that we understand what defines them as a subject. In order to simplify the notion of cognitive self-representation, we will develop two notions that define the individual according to her interactions with the environment:
 - The cognitive body: the perceiving, sensing, and corporeal envelope that emerges from the interactive experiences and opportunities afforded by the environment
 - Self-identity: awareness of one's individuality and singularity
- 8 Based on the theories of embodied cognition, the cognitive body can be defined by two types of representations:
 1. Functional representations of the body derived from a body schema which depicts the dynamic internal representation of the body's spatial and biomechanical properties (Viaud-Delmon, 2007). The body schema is derived from an individual's homunculi (motor and sensory cortical mapping) and somatognosia (awareness of the parts of one's body and of their spatial relations). This schema has alternately been considered an immutable and specific trait of the individual representative of its species (Dolto, 1984), or as an evolutionary and dynamic feature, acquired progressively (Ajuriaguerra, 1980). This representation emerges from sensorimotor input taken in by the functional body, as a result of its actions and subdivision into different constitutive dimensions: shape, size, position, and location of body parts and organs; and from the data taken in by the sensory body, as a result of different types of sense-based input, which can either be exteroceptive, such as visual, tactile, and auditory data, or proprioceptive. These representations are perceived by the individual thanks to the integration of its different sensory channels, and simultaneously understood thanks to its cytoarchitectonic organization (arrangement of cells and nervous pathways) as well as through conscious empirical skills acquired through somatognosia.

2. Affective representations of the body, which allow for the development of one or several body images influenced by self-esteem. These precarious representations, steeped in affect and interpersonal relationships, are rooted in the subject's personal history (Dolto, 1984). Head and Holmes (1911) argue that body image is an internal representation born out of an individual's conscious experience, informed by visual, tactile, and motor information. Originating in the body, it results from the subject's acquired interactions with her environment. Body image is thought to influence perception-action patterns by enabling the subject to project action-solutions into the world that are compatible with her self-image, and thus interpret the environmental response (Berthoz, 2004).

- 9 It follows from these notions that the subject develops a representation of her cognitive body by combining body schema and body image (Fig. 1). The individual can hardly be called a mere organism perceiving and acting in and with its environment; it is also an entity unto itself, with an individuality and an identity that allow it to differentiate itself from others. The notion of cognitive body representation does not therefore fully constitute cognitive self-representation. Thanks to this theoretical examination, we may now arrange the above notions into a chart, moving from the most physical and organic at the left to the most abstract and cognitive at the right.

Figure 1.

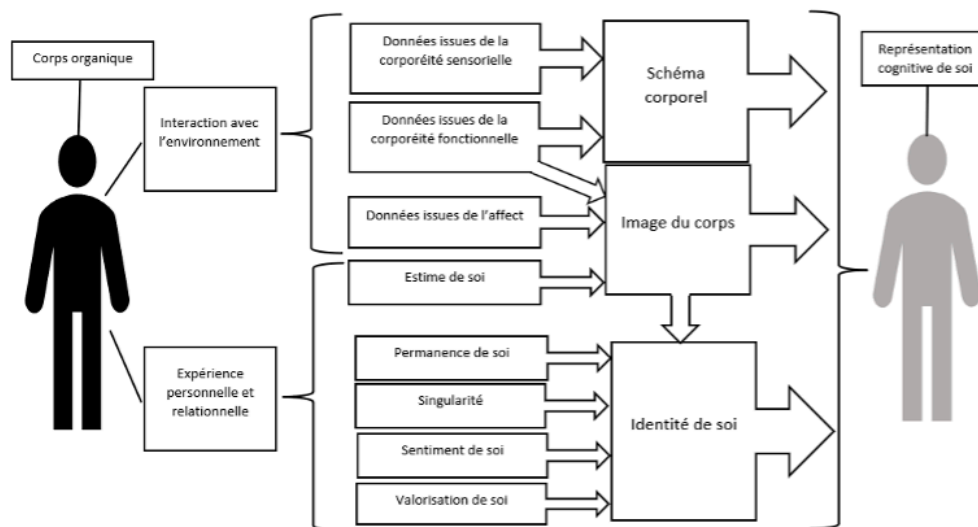


Diagram detailing the process of cognitive self-representation.

Credit: Kevin Beaufils & Alexis Berland.

- 10 The above chart shows that the cognitive body does not alone constitute cognitive self-representation. It is usefully supplemented by the notion of self-identity, which the individual requires in order to relate to her cognitive body as more than a mere instrument. Self-identity is suggestive of an existential continuity developed through time (Tap, 1987). This lasting consciousness is considered to result from a pattern of differentiation between self and non-self, based on the localization of sensations, tensions, and emotions experienced by the body across the evolutionary and empirical process of individualization (Lipiansky, 2005). Personal identity is inseparable from

corporeal representations, giving coherence and dynamic direction to one's entire being by defining it in a stable way.

- 11 Furthermore, Codol (1981) states that identity can be defined according to various dimensions: self-image, firstly, followed by self-awareness, self-differentiation, self-uniqueness, self-permanence, and self-worth. Self-worth is not only about claiming to have what are viewed as positive qualities, but rather
it also and most importantly consists in claiming to have a certain power over one's environment [...]. Having the feeling that one can influence things and beings, direct or control events, at least partially, is correlative of any positive self-image. (Codol, 1981, p. 116)
- 12 Taken together, these dimensions bring us closer to the concept of agency, defined by psychology as an individual's subjective perception of her own self as an agent capable of acting in the world and of generating events. Agency hence challenges the subjective perception of a passive self merely subjected to events. An additional dimension is self-esteem, which seems to affect cognitive self-representation. From a reflexive standpoint, the individual's representation of her own capabilities, or metacognition, influences the development of her body image and cognitive identity (Fig. 1).
- 13 Combined, the emergence of the cognitive body and the development of self-identity allow for the presence of cognitive self-representation. In order to be effectively embodied in an avatar, however, this representation must fall in line with the features of the digitally simulated body, which then serves as a vessel through which the user may interact with the virtual environment (Fig. 2).

Figure 2

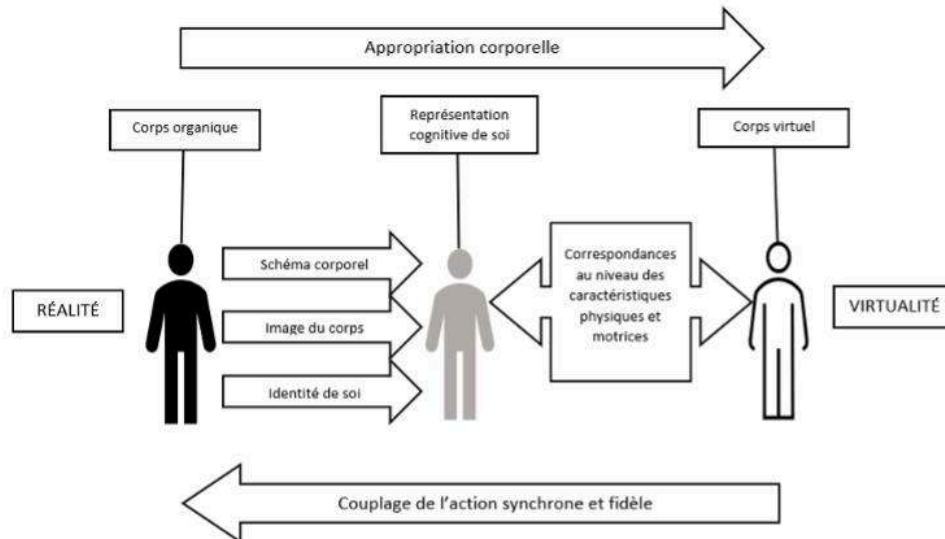


Diagram of body ownership, occurring through the projection of a user's cognitive self-representation onto a simulated digital body.

Credit: Kevin Beaufils & Alexis Berland.

The avatar as a digitally simulated body

- 14 In VR, avatars allow users to be embodied in a more or less virtual vessel inside a digital world. The term *avatar* originally referred to Hindu divine incarnation before the term

was subsequently taken up in a number of fields. Nowadays, it refers to the representation of a user on the Internet (forum, platforms), in video games, or in immersive virtual environments (Georges, 2012). This representation is central to the user's visual embodiment in the avatar. The relationship between the user and her avatar is largely influenced by the physical and aesthetic characteristics of the latter, as well as by the way it is operated and the symbolic charges it conveys. This relationship may explain the tendency toward permeability, or even erasure, of the boundaries separating the user's identity from that of the character. Studies have shown that avatar features (shape, build, clothes) have a direct impact on users' behavior and self-esteem (Ratan *et al.*, 2019). This is referred to as the *Proteus* effect (Yee & Bailenson, 2007), which supports the idea that mental and affective representations of the digital body, in this case the avatar, alter an individual's actions, movements, and thoughts.

- 15 The avatar, as a corporeal mediator connecting the individual to the immersive digital world, doubles the individual's "own body," in the sense of Merleau-Ponty (1945): the carnal body is doubled by a virtual body, which is the medium the subject relies on to exist in the immersive context. In the context of avatarization, the individual may have to depart from her body schema in order to recreate a new corporeal representation anchored in the particular physical features of the avatar, in the case where the identified body of the avatar is entirely distinct from the user's (Viaud-Delmon, 2007). This departure favors effective control of the avatar and of its motions without disturbing the user's original body schema. In order to improve one's sense of presence in an immersive setting involving a corporeal intermediary, the avatar should be a faithful copy of the individual's own body, such that the corporeal mediation may go unnoticed by the individual (Lombard & Ditton, 1997). In this way, the avatar serves as a simulator of the individual's own body, placing the user in a situation of experienced corporeal ecology. This means that we can expect a better transferability of skills acquired *in vivo* to virtual reality, and conversely, of skills acquired *in virtuo* to real life.
- 16 However, this transfer can only take place if the user is able to move past fundamental differences that separate her own customary body from her digital body.

Perceptual differences between the physical and digital body

- 17 While first-person view has traditionally prevailed in VR, avatars seen in third-person view have appeared in recent years. In first-person VR experiences, the relationship which usually takes shape between an individual and her digitally simulated body relies principally on vision, which can sometimes find itself at odds with other systems tasked with anchoring it in reality, such as proprioception, kinesthesia, and equilibrioception. The user must allocate part of her cognitive resources to each of these systems while simultaneously experiencing a situation of corporeal bilocation (Amato, 2008; Furlanetto *et al.*, 2013; Perény, 2015; Amato *et al.*, 2017). Navigating these two overlapping worlds at once, the individual's own body moves around the physical world while steering another virtual corporeality throughout the immersive world.
- 18 The main difference separating the physical body from the digitally simulated body has to do with the absence of the other senses that serve to identify the body's position in

physical space and, consequently, to represent it: proprioception, haptic perception, and kinesthesia. A human being who is unable to see the physical world is forced to produce sensory compensations via multisensory integration. Unlike people afflicted with blindness and who potentiate their senses to make the best use of sense-data—as expressed by the notions of multimodal compensation and vicariance (Berthoz, 2013)—participants in VR experiences mainly rely on their visual system to interact and move around in the environment.

- 19 The second difference between the physical body and the digital body concerns the digital body's immateriality. If we go back to the theory of embodied cognition, corporeal representation emerges from one's interaction with the environment. The absence of haptic and tactile feedback from actions performed in relation with virtual objects hinders the user's capacity to recognize and identify the avatar as a substitute body allowing her to navigate an environment that is closed off to her physical body. In order to develop an adequate sense of body ownership, the user must then develop compensation mechanisms that are once again predominantly based on her visual system. The replacement of the vestibular system raises another issue (Berthoz, 2014): how can the simulated body convey the illusion of the physical body's motions? Though we cannot replace vestibular perceptions, one solution has to do with a useful illusion of self-motion that makes it possible for the brain to overcome perceptual contradictions:vection.
- 20 The third difference follows from the technological limitations that still exist today. Although interactive technology tends to work in real time, digital computation produces a minor latency (Couchot, 2015). Where this latency is perceived, it can lead to a feeling of discrepancy between the moment when a movement is performed and its visual perception. This means that the embodied avatar's movements "must respect certain basic primitives that do not violate the perceptual thresholds beyond which the subject becomes a mere spectator of the motions of the avatar meant to represent her" (Viaud-Delmon, 2007, p. 40). These basic primitives refer to the biomechanical properties of the user's body.
- 21 Digital body ownership is hence an active process that relies on the user's perception of her avatar. The avatar is a digital technological tool that allows the user to ignore the differences between her biological body and her digital body by engaging in and gaining command of a new perceptual space, to the point that she becomes her own avatar.

Body ownership: the embodiment of cognitive self-representation in the digital body

- 22 It is our contention that the sense of owning an avatar's body depends on a successful alignment between cognitive self-representation and the digitally simulated body, as determined by similarities between the two bodies, their affective and perceptual dimensions, and the projection of the individual's cognitive identity onto the new body (Fig. 2). Yet its success also and most importantly relies on how the individual perceives the digital body and its action inside the virtual environment, as demonstrated by sensorimotor theories of perception.

Sensorimotor theories of perception

- 23 According to sensorimotor theories of perception, perception actively extracts relevant data from the environment by identifying invariants (Gibson, 1966, 1979). Perception is a process (Havelange *et al.*, 2002) that relates to the environment through direct coupling, and one that builds on the identification of patterns between actions performed and resulting sensory feedback (Auvray & Fuchs, 2007): we perceive in order to act and we act in order to perceive.
- 24 In virtual immersion, motor theories of perception assume a relation of codependence between processes of interaction and immersion. Interaction with the technological device—or tool—is once again at the heart of the immersive experience, giving rise to a new perceptual space.
- 25 Generally speaking, the use of a new tool transforms the way human beings relate to their environment, both in terms of action and sensation, which also shapes new spaces of perception and action. Binoculars, for instance, give their user the feeling of being in a different place from her sensory organs. Avatars similarly provide a new tool for interacting with a virtual environment, and similarly give rise to a new space of perception and action. The user tends to forget the avatar, which appears as an object transforming the conditions of action and hence the conditions of the perceptual field (Fig. 3). The technical set-up used in virtual reality—a VR headset, combined with an alternative mode of control and motion—tears the user away from her space of organic perception and action to teleport her into a new space (Amato, 2011). The presence or absence of the avatar defines how the user perceives and acts within this space, depending on two different bodily frames of reference. Unlike what happens in first-person view, the avatar in third-person view becomes a perceptual and interactive tool that is visible in the new virtual environment.

Figure 3

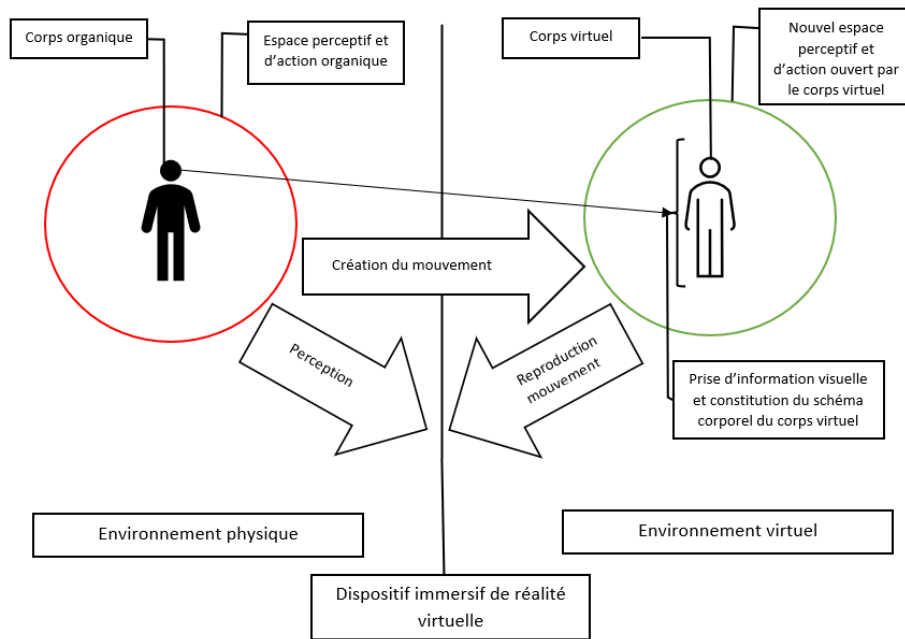


Diagram of the avatar as a tool generating a new space of action and perception within the virtual environment.

Credit: Kevin Beaufils & Alexis Berland.

The body's frame of reference in virtual reality

- 26 Although it can be argued that first-person view is closer to organic perception, this perception mode fails to take into account the user's organic body, which is left out of the synthetic environment. Viaud-Delmon (2007) nevertheless argues that VR primarily draws on a cognitive space informed by dynamic spatial representations of the environment. The fact that the subject does not actually move around therefore does not preclude the emergence of a space of action which only exists through a mental imagery of actions, even in the absence of sensory integration. VR immersion and embodiment are part of a bidirectional process described as both bottom-up (emerging, built from the senses up) and top-down (descending, derived from cognition). According to the same author, the egocentric space shaped by body schema ownership also comes into play, although it is usually less active in VR experiences.
- 27 Using an avatar that projects an image of the body helps the user develop a body schema of the embodied entity interacting with the virtual environment. A representation of the avatar also makes it possible to navigate a space of action (Viaud-Delmon, 2007) more effectively than first-person view. Visual feedback from the user's actions facilitates the user's interactions with the environment. Finally, the represented avatar creates a frame of reference in the virtual environment, giving the user access to a new cognitive space. The individual's sense of ownership over the avatar body emerges when she is able to transfer her cognitive self-representation to her new digital body, which stands at the center of her perception. She is then able to grasp the virtual environment from an egocentric point of view (Slater & Wilbur, 1997; Slater *et al.*, 2010), even if the avatar's appearance does not resemble the user's. For a

successful embodiment, the perception of the virtual body and the information it conveys must correspond to the user's actual movements, which requires faithful replication on the part of the avatar.

The importance of the avatar's resemblance to the user's physical body

- 28 The avatar's appearance plays a central role in building a sense of body ownership. Several contemporary authors have argued that the body schema is flexible (Berthoz, 2010; Blanke *et al.*, 2004), which makes it possible for users to get a fast grip on avatars in video games and VR environments. Several studies have shown that the degree of likeness has an impact on users' sense of immersion, sense of presence, and sense of embodiment (Gorisse, 2019; Slater *et al.*, 2009). The avatar's resemblance is defined according to three criteria:
- 29 1. synchronicity, defined by the avatar's reaction time with regard to the user's movements
- 30 2. behavioral resemblance, i.e., the avatar's dynamic properties, including body animation and facial expressions, and resemblance in the way it interacts with its virtual environment
- 31 3. visual resemblance between avatar and user, through anthropomorphic realism and accuracy (how much the avatar looks like the user) (Garau, 2003; Mansour *et al.*, 2006).
- 32 Based on this premise, we believe that user-like avatars allow for a heightened sense of body ownership. Indeed, recognizing oneself in an avatar produces strong consistency between the user's cognitive representation and the digitally simulated body. Evidence suggests that the avatar's visual resemblance, and its accuracy in particular, can help increase one's sense of embodiment in an immersive virtual environment (Gorisse, 2019). Yet avatar resemblance comes up against certain limits, as expressed by subjects' feelings of uneasiness toward avatars, described in the disturbing phenomenon of the "uncanny valley" (Mori, 1970). Digital self-representation forms an asymptotic curve tending toward a complete and yet unattainable resemblance with the physical body.

The case of the autoscopic self-avatar

- 33 We have every reason to believe that in addition to the user's ability to transfer her cognitive self-representation, body schema (situated body), body image (identified body), and cognitive identity from her biological body to her simulated digital body, a successful embodiment also relies on her ability to accept this virtual body as an integral part of herself. In the case of a visually resemblant self-avatar, the situated body and the identified body are coupled together, inviting a more effective transfer of cognitive self-representation and reinforcing the user's embodiment in her virtual avatar. Developing a body schema in relation to the digital entity occurs almost immediately, because the properties of the virtual body are similar to those of the physical body, and the user can interact with the virtual environment without disturbing her own body schema. The challenge consists in creating a situation that helps the user project her own body image inside the virtual universe, thanks to a third-person view, so as to create an autoscopic situation in which the individual sees herself in an obvious and indisputable way (Blanke & Mohr, 2005; Amato *et al.*, 2019).
- 34 In this case, the sense of ownership calls for a prior sense of self-recognition. In a first perceptual phase of the user/avatar relationship, the user's visual system detects similar features in the avatar (build, hair, clothes). This is followed by a second sensorimotor phase of action-based identification. These two phases, detection and action-based identification, make it possible for the individual to project her cognitive self-representation onto the avatar. Self-identifying with the avatar paves the way for a delegation of agency, to the extent that users can perceive and even feel through their avatars, practically putting themselves in the avatars' shoes. This growing familiarity with, and command of, the self-resembling avatar encourages a mediation of agency and the delegation of intentionality (Gaon, 2013).

Self-esteem and the affective body in relation to self-recognition and body ownership

- 35 The relationship between body ownership and a self-avatar is influenced by numerous interindividual specificities. We mentioned earlier that affect and self-esteem played a decisive role in shaping our self-image. The individual's familiarity with her own image can influence her relationship with her avatar. It sometimes happens that the user does not recognize herself in the avatar, even if it is her exact replica. Taylor (2002) has shown that certain gamers identify more deeply with their avatars than they do with their own image. This can be explained by the number of hours spent observing their virtual body, compared to the time spent observing their own image in front of a mirror, for instance.
- 36 Research also highlights self-esteem's impact on the reactions and emotions elicited by a virtual double (Park, 2017). Because psychological factors have an impact on user experience, we must take self-esteem into account, as well as its potential impact on the selection of avatars displaying different degrees of likeness.
- 37 In immersive VR experiences, the avatar is often cut off at the arms or hands, which can limit its use by psychotic audiences suffering from body fragmentation anxiety. However, advances in technology have sought to work the subject's real hands and arms into the immersive experience, though the legs are often still absent. Working

these aspects into a simulated context helps the user maintain visual contact with her own body (Courville, 2013) over the course of the experience. Some mixed-reality devices (Milgram & Kishino, 1994) offer atypical solutions designed to include the user's usual body in the digital world, such as in the immersive experience "Become an Avatar," initiated by researchers Perény, Amato, and Berthoz (Pereny *et al.*, 2016).

Influence of body ownership on the individual's sense of immersion and presence in the virtual environment

- 38 This paper echoes the general consensus regarding the definition of immersion as a person's sense of having left the real world and of being enveloped in and by the virtual environment through a computational system's ability to generate inclusive, extensive, surrounding, and vivid illusions of reality (Slater & Wilbur, 1997). The user receives multimodal sensory input through the technology used (Bystrom *et al.*, 1999; Draper *et al.*, 1998; Slater & Wilbur, 1997). In this definition, Slater & Wilbur (1997) emphasize the need for self-representation, such that the virtual body centers perception, in order to experience immersion in a virtual environment.
- 39 If perception is an observer's active construction, cognitive immersion must be understood as an active attunement to a new technological device wherein developing a sense of presence is only one in a series of steps. This implies placing the interactive process back at the heart of immersion.
- 40 Immersion and presence seem inherently intertwined. An individual's sense of presence can be defined by the psychological perception of being there, inside the virtual environment where the person is immersed. Studying this feeling means trying to determine by which reality the user is primarily affected. Following our theoretical line of approach rooted in embodied cognition, a user's sense of presence emerges from the representation of her body's movements in relation to the actions she performs in the virtual environment. This accounts for the use of the term "embodied presence" (Schubert *et al.*, 1999).
- 41 An avatar user's sense of presence plays out on several levels. Environmental presence depends on how the virtual environment reacts to the person's actions over the course of the virtual immersion. Corporeal presence corresponds to a sense of embodiment in the virtual body. The sense of being physically present during the immersive experience is a mental perception based on an attentional process and a mental modeling of the virtual space (Schuemie *et al.*, 2001). Finally, personal presence refers to the subjective feeling of being in the virtual environment and to the reasons invoked by the individual to account for the phenomenon.
- 42 If behavioral and interactive features are sufficiently close, reflexes acquired in the real world easily transfer into the virtual world (Auvray & Fuchs, 2007). The user can then base her sensorimotor activity on a schema acquired in the real world. The relationship between the user, her avatar, and the virtual environment generates a virtuous circle. Successful embodiment in the avatar allows for a successful interaction with the virtual environment, which increases one's sense of immersion and the acceptance of the avatar as a new perceptual and interactive tool facilitating embodiment. The relationship between the user and her avatar therefore promotes self-recognition and an effective transfer of part of the user's cognitive systems, making it possible to act

and interact effectively with the environment through a process of mediated embodiment.

Conclusions on the positive effects of avatar embodiment and possible applications

- 43 Studies involving the use of VR avatars have repeatedly concluded that the first-person view remains an effective means of immersion, thanks to a natural transposition of our perceptual mechanisms (Gorisse *et al.*, 2017). This point of view offers the best conditions for precision interactions, i.e., interactions that require finely tuned movements performed at close range. Third-person avatars, as a vantage point and an instrument of embodiment and immersion, nevertheless offer many advantages in a virtual environment. First, the third-person view avatar makes it possible to develop a sense of embodiment when the avatar is perfectly synchronized in terms of its visual and motor features. Second, third-person view avatars offer a better perception of the environment, which promotes the development of new use-cases for virtual reality. Finally, avatars are a source of visual feedback and of cognitive analysis in connection to the actions performed in the virtual world. This kind of avatarization provides the user with a materialized double capable of transforming her self-image through the role of mirror neurons and by linking perception and action (Berthoz, 2004).
- 44 To foster a better sense of immersion, this paper suggests designing self-resembling, or “autoscopic,” avatars. Avatars of this kind appear to foster a sense of body ownership because they generate similar immersive effects as those obtained in first-person view, while simultaneously retaining the advantages of third-person view. The features of self-avatars are currently being explored by Beaufils as part of his PhD dissertation, *A Comparative Study of Cognitive Transfer with a Virtual Protagonist: the Mediated Cognitive-Sensory Relationship between Humans and Avatars in Virtual Reality* [Étude comparative du transfert cognitive avec un protagoniste virtuel: la relation cognitive-sensorielle médiatisée entre humain et avatar en réalité virtuelle], which will explore whether self-recognition indeed promotes a better sense of body ownership, immersion, and presence in the virtual environment. His expected results, namely, that an effective sense of ownership is likely to improve cognitive transfer, supports our hypothesis of a partial transfer of cognitive skills (such as attention, recognition, action planning, perception, and feeling) from the user to the virtual protagonist.
- 45 Because avatarization relies on a simulated projection of abilities in relation to the avatar’s physical features, we argue that self-avatars help avoid the inhibition of preexisting corporeal representations and promotes their exact projection onto the digital body in a way that simplifies the development of a sense of body ownership. Self-avatars therefore appear as a potential way to reinforce the user’s cognitive transfer through self-recognition, simultaneously promoting identification and a faster coupling of the user’s body schema with her avatar, in addition to a better transposition of perceptual mechanisms and cognitive processes.

- 46 Self-avatars hence seem to enhance one's sense of presence over the course of the immersive experience and to promote the transfer of skills from *in-virtuo* to *in-vivo* experience. The effectiveness of VR technology for health and training purposes could hence be improved by self-avatars, an aspect likely to benefit the many people offering VR experiences around the world.

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ABSTRACTS

Virtual reality experiences often use avatars to enhance their immersive potential, tapping into cognitive processes by which their bodies are perceived as our own. This in turn supposes that we are able to embody our cognitive self-representation in the avatar and accept the digital representation of this virtual body as an integral part of our identified body. This paper explores how the theory of embodied cognition accounts for the relationship between cognition, body, and environment. It further elaborates on the process of cognitive self-representation through notions of cognitive body, self-identity and goes on to define the avatar as a digitally simulated body, outlining its perceptual differences with the physical body. Finally, the process of digital body ownership is described according to sensorimotor theories of perception, while self-resembling avatars are identified as particularly conducive to embodiment.

INDEX

Keywords: avatar, virtual reality, cognitive representation, embodiment, embodied cognition, perception, immersion

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