Bodily boundaries and beyond:

Exploring the malleability of bodily self-consciousness

An interview with Bigna Lenggenhager

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Abstract

In this interview, Bigna Lenggenhager discusses her groundbreaking empirical work on bodily self-consciousness, bodily disorders and bodily illusions. The conversation explores issues related to the interpretation of the rubber hand illusion and the full-body illusion, the nature of the relationship between self-consciousness and bodily awareness, syndromes of disembodiment, as well as the use of virtual reality as a therapeutic tool for bodily disorders.

keywords: *self-consciousness, bodily awareness, rubber hand illusion, full-body illusion, virtual reality*

What sparked your interest in bodily self-consciousness? What types of questions were you aiming to answer by entering this field?

As a child, I read, or rather tried to read, many of my father's books on yoga, meditation, and Buddhism. Although I didn't understand much, I was fascinated by the different understanding of the self, life, and death in these traditions. Later during high school, my desire grew to study the human brain in its complexity, hoping to find answers to some of the big questions about how we perceive, think, and act, and why we are who we are. I went to university to study psychology, psychopathology, and neurophysiology.

During this time, I got interested in illusions and their value in revealing how the brain works. I was intrigued by visual and multisensory illusions, but above all by bodily illusions, such as the rubber hand illusion (Botvinick & Cohen, 1998) and Pinocchio illusion (Lackner, 1988). I found it fascinating how easily the perception of the most familiar object, i.e., one's own body, can be altered by just using a clever experimental design and without any drugs or long meditation techniques. But definitively the strongest driver of my interest in bodily self-consciousness were the patients I investigated during my first internship in the Neurology Department of the University Hospital of Zurich. Listening to their stories made me want to understand everything about how we perceive our body and how it links to our sense of self and consciousness. Realizing how many aspects of the perception of the self can be altered, I wanted to learn why and how we normally perceive our body (but not another person's body) as belonging to us, how we feel in control of our body, and how we perceive and act from a physically embodied perspective.

There are many disorders of bodily self-consciousness. Is there a specific condition that elicits a particular fascination for you?

From the external perspective as a researcher, all disorders of bodily self-consciousness are extremely fascinating to me. It is impressive how many different aspects of bodily self-consciousness can be affected. I think this broad range of symptoms makes bodily self-consciousness disorders so fascinating, ranging from the feeling of being duplicated or even multiplied, as in a specific form of heautoscopy (Brugger et al., 2006), or the feeling that one does not exist, as in Cotard syndrome.

What's more, different disorders fascinate me for different reasons. Take for example, out-of- body experiences: I find it extremely fascinating that these experiences have been described in so many different contexts and cultures, and that they might actually have shaped the way people think about the relation between the body and the mind, and between life and death. And the fact that such complex illusions can be induced by local brain stimulation (Blanke et al., 2002) remains fascinating to me.

Another example is Body Integrity Dysphoria, a disorder in which otherwise healthy individuals feel like a part of their body does not belong to them (Brugger et al., 2013). Here, the most fascinating aspect for me is probably the related societal and ethical questions, which heavily depend on our conception of how body, brain, and mind are linked.

In 2007, you published the first experimental study investigating the so-called full-body illusion (Lenggenhager et al., 2007). Since this landmark publication, you have done pioneering work on various versions of this illusion that have yielded a wealth of insights on the multisensory neural mechanisms underlying bodily self-consciousness in humans. Could you describe the basic setup of the full-body illusion, and summarize the main insights that you have derived from your work on this illusion?

In the mentioned study, we tried to bridge the knowledge and theories about the fundamental mechanisms of out-of-body experience (Blanke et al., 2005) with at that time recent insights from the plasticity of the bodily self in healthy participants using multisensory stimulation paradigms. We tried to extend the technique used in the famous rubber hand illusion paradigm (Botvinick & Cohen, 1998) using 3D video-based virtual reality systems to create more autoscopic or out-of-body-like illusions. We had great fun in the lab exploring and trying out many versions of such illusions.

In the final setup, participants were shown their own (or an object's or a mannequin's) body projected two meters in front of them. Then, by touching their back while displaying it synchronously (as compared to asynchronously) on the body projection, we enhanced self-identification with their projected body, which also led to a change in perceived self-location.

For me personally, the most interesting finding of this study was that we not only altered the perception of a single body part, as during the rubber hand illusion, but that even the perception of the whole body and self can be changed. This is interesting from a theoretical perspective but might also spark potential therapeutic applications (see e.g. (Pamment & Aspell, 2017)).

In a commentary from 2010, Adrian Alsmith writes the following about full-body illusions:

> "Unfortunately, the question of whether or not there are full-body illusions is empirically under-determined, as putative full-body illusions are difficult to isolate from illusions involving composite parts that do not constitute a 'full' or 'whole' body. That is to say, a plausible alternative is that only representations of the body parts directly stimulated become subject to the experimentally induced bias, whilst other parts remain relatively (perhaps even completely) unaffected." (Smith, 2010)

In other words, Alsmith suggests that the so-called full-body illusion might in fact be something like a "trunk illusion" in the classic setup. Do you think this is plausible? How do you think this question could be empirically settled? For example, if multiple body parts were stroked instead of just the trunk, would you expect to see a change in the effect size of implicit measurements and questionnaire reports?

I agree with Alsmith that with our experimental setup, we cannot differentiate between these two alternative explanations. We asked the participants in the self-location task to go back to "where they were standing before". This question/measure does not allow us to localize the trunk in a different place than let's say the arm. I think it would be rather easy to experimentally test Alsmith's hypothesis, both by stimulating more and different body parts (as in (Salomon et al., 2013)) or by using more sophisticated self-location measures in virtual reality that could be easily adapted to different body parts (Nakul et al., 2020). However, I do not think that his alternative explanation is very likely. Firstly, none of the participants has ever reported a sense of disruption or fragmentation of the body (which would, of course, be very interesting but does not seem very common in clinical conditions either). Secondly, a study of Ehrsson's group (Gentile et al., 2015) looked at generalizability of ownership from the stroked body part to the full body. Even if their setup was slightly different – with a full body illusion from the first-person perspective – the results clearly show that the sense of ownership spread to the non-stimulated body parts.

> "We not only altered the perception of a single body part, as during the rubber hand illusion, but even the perception of the whole body and self can be changed."

The rubber hand illusion (Botvinick & Cohen, 1998) represents the pioneering and most widely used experimental paradigm to temporarily alter body ownership by transferring the sense of ownership from one's own arm to an artificial body part. Synchronous stroking of the participant's concealed real hand and visible rubber hand, so that the felt touch of the brush on the real hand and the seen touch on the fake hand are closely matched, induces a sense of ownership of the artificial limb. Broadly accepted theoretical frameworks maintain that the rubber hand illusion reflects the role of multimodal integration in embodiment (Suzuki et al., 2013), indicative of the brain's attempt to rectify discrepant multisensory visuotactile information.

However, recent criticism contends that existing interpretations overlook the role of trait differences in the ability to generate experiences that meet expectancies (phenomenological control) (Lush, 2020). Demand characteristics, specifically participant expectancies and stable trait suggestibility, could account for the rubber hand illusion experiences by "generating expectancies which are met by the voluntary top-down control of phenomenology" (Lush, 2020, p. 1), similar to imaginative suggestibility within the context of hypnosis. This line of argumentation rests on empirical results evincing that measures of the rubber hand illusion are substantially related to hypnotic and sensory suggestibility (Fiorio et al., 2020; Marotta et al., 2016; Walsh et al., 2015), and that expectancies predict illusion scores (Lush et al., 2019).

Do you think that measures of the rubber hand illusion may be confounded by the active generation of phenomenological control? If a lack of control of demand characteristics truly exists, how could rubber hand illusion measures be improved? Would the aforementioned criticisms extend to full body illusions as well, particularly those completed in virtual reality, which would not entail contradictory proprioceptive information between the real and artificial body part?

Yes, I think it is certainly worth it and important to follow up this line of research and alternative explanations in more detail and with solid experimental methods. Other than in classical visual illusions, like the Müller-Lyer illusion (Müller-Lyer, 1889), which are perceived by everyone and extremely stable between participants, in bodily illusions we typically observe strong individual differences in how they are perceived and how strongly people react to them. On the other hand, when you observe how people react to walking over a virtual plank in the air, like in Vive's plank

simulation, you can tell that even if they have insight into the experimental setup, the body reacts as if they didn't. I agree that individual differences could partially be caused by differences in suggestibility, and I find it surprising myself how little research directly addresses why people react so differently and what potential underlying mechanisms might be at work. I think it is generally important to put more effort in understanding differences between various individuals and also between various settings, but do not think that demand characteristics can explain everything. Sebastian Dieguez recently suggested, in a critical comment to one of our papers, to call bodily illusions rather "aliefs" (Dieguez, 2018). He suggests that such aliefs depend on motivation and expectancy of the participants, which is very much in line with Lush's findings. But I think, even if future empirical work would indeed show that demand characteristics are the or an explanation of bodily illusions, it does not make the findings of the bodily self literature less interesting (Roel Lesur et al., 2018). Over the last 20 years, a vast amount of studies have shown that with bodily illusions, many different physiological, emotional, and cognitive aspects can be altered. For example, hippocampal activity underlying autobiographical memory (Bergouignan et al., 2014), implicit peripersonal space measures (Noel et al., 2015), and immunological response (Barnsley et al., 2011) have shown to be modulated by bodily illusions. If these processes can all be modified by phenomenological control in the predicted way, this would seem quite impressive to me. Together with you, Jasmine, we are currently investigating the link between embodiment, illusory embodiment, and placebo response, which I think is a promising research path to continue. A further aspect that I think might be difficult to explain with phenomenological control are the increasing findings in animals on "bodily illusion", suggesting that there are physiological changes specifically to the illusion condition (e.g., Shokur et al., 2013; Wada et al., 2016). This is, by the way, another line of research that I think would be exciting to follow up. For example: how does firing rate of place or grid cells change after a full body illusion in rats? This would be a much more implicit measure of self location than the one we used in our first study you mentioned above.

Regarding the question on how we can improve current research, I think it would be important to develop more implicit measures, but also (try) to

replicate the many interesting implicit measures in humans and animals that have already been described, ideally in much bigger sample sizes. This is important, as some of these beautiful data have not yet or only rarely been replicated. Bigger sample size would facilitate the assessment of individual differences and to link different implicit measures with phenomenological changes.

To follow up on the points above, the rubber hand illusion is classically considered a measure of body ownership. Yet, accumulating evidence suggests that body ownership and self-location constitute distinct aspects of bodily self-consciousness (Serino et al., 2013). While explicit measures of body ownership are assessed by means of a self-report questionnaire, proprioceptive drift towards the rubber hand is generally considered an implicit measure of body ownership. However, if proprioception measures the shift of the own arm towards the rubber hand, would implicit proprioceptive drift not more accurately constitute a representation of self-location rather than ownership? Considering that these implicit and explicit measures of the rubber hand illusion further seem to be substantially yet differentially related to hypnotic and sensory suggestibility, would a reform or at least more specific operationalization of the rubber hand illusion measures be warranted?

Yes, I would agree. A measure that might be more directly linked to the sense of body ownership than the proprioceptive drift might be, at least conceptually, the electrodermal activity to threat (Armel & Ramachandran, 2003). However, there are also some problems with this method and we often find diverging results between threat measures and self-report questionnaires (e.g., Roel Lesur, Weijs, et al., 2020). As mentioned above, I think it will be important to relate the different measures of the rubber hand illusion to different phenomenological measures and also to potential confounding differences (e.g., the aforementioned suggestibility). For that, I think it will also be important to further develop the explicit measures we use, and I am very optimistic that some of the measures you, Raphaël, apply, like microphenomenological interviews combined with EEG based biomarkers (Timmermann et al., 2019) might advance this research direction.

The notion of "first-person perspective" (1PP) is widely used in the scientific literature on the full-body illusion and virtual reality (e.g., Blanke & Metzinger, 2009). However, its definition is not always consistent across publications. Here are a few examples:

> (a) “the feeling from where 'I' experience the world around me” (Pfeiffer et al., 2014; see also Ionta et al., 2011; Blanke, 2012).
>
> (b) “the point from which visual information from the environment is gathered” (Maselli, 2015).
>
> (c) “the experience of taking a first-person, body-centered, perspective on [one's] environment” (Serino et al., 2013).
>
> (d) “a purely geometrical feature of an egocentric model of reality [which] includes a spatial frame of reference, plus a global body representation, with a perspective originating within this body representation” (Blanke & Metzinger, 2009)
>
> (e) “the experience of being a subject and of being directed at the word” (Pfeiffer et al., 2016).

Many of these definitions (e.g., a, c and e) explicitly describe 1PP as an experience, but some (e.g., b and d) do not. Furthermore, some definitions include a reference to bodily representation, while others merely refer to the information conveyed by visual experience.

Beyond these lexical discrepancies, it seems that there is a broad difference between two ways of operationalizing the notion of 1PP. Some studies seem to construe 1PP as the subject's awareness of the egocentric location of the point of origin of her visuospatial spatial perspective – i.e., the location from where the subject sees their environment. Other studies seem to construe 1PP as the subject's awareness of the orientation of their head or body with respect to a geocentric frame of reference – e.g., whether the subject is looking up or down with respect to gravitational cues.

Presumably, these two constructs are not equivalent. Blind individuals (or sighted individuals wearing a blindfold) lack a visual perspective, but can nonetheless be aware of their orientation with respect to gravitational cues. Conversely, sighted individuals can become temporarily disoriented (for example because of vertigo, zero G, or galvanic vestibular stimulation), while remaining aware of the location from where they see their environment.

Do you think the notion of 1PP should be disambiguated, such that more specific constructs can be investigated empirically, or do you think the apparent discrepancies between construals of the notion can be reconciled in a single construct?

It is true that there are many different definitions and conceptions of the first-person perspective. Defining the first-person perspective as a visuo-spatial perspective, in my opinion, neglects our multisensory perception of the world, the body, and ourselves. This, I think, reflects the classical very strong dominance of vision and visual research in science. Thus, I would argue that at the very least, it should be called and considered as an audio-visuospatial perspective, since we clearly have an auditory egocentric perspective as well. It can be experimentally manipulated as well, similar to the visual one (e.g., Lesur et al., 2020) and can also be mismatched in rare clinical conditions (Blanke et al., 2004). Furthermore, as you mention, the gravitational perspective is also important and often neglected. But rather than disambiguate the notion of the first-person perspective, I think it is important to consider that in normal waking consciousness, our first-person perspective is based on the integration of these different perspectives. I think it is interesting and important to experimentally take them apart and investigate how they affect various other aspects of self-consciousness, such as for example self-location. To give an example, let's say the auditory perspective is different from the visual, where would you feel localized? At either one or the other perspective, alternating, bilocated, or somewhere in between?

Similarly, one might wonder whether the notion of "self-location" – also widely used in the scientific literature on the full-body illusion and virtual reality – could benefit from disambiguation. Self-location is often defined as "the experience of where I am in space" (e.g., Ionta et al., 2011; Blanke, 2012; Blanke et al., 2015; Pfeiffer et al., 2014).

In the full-body illusion with front stroking, three notions of self-location can potentially be distinguished:

1. The subject's awareness of the location of the point of origin of her visuospatial perspective in an egocentric frame of reference.

2. The subject's awareness of the location of her own body – that she sees in front of herself – in an egocentric frame of reference.

3. The subject's awareness of her location in an allocentric frame of reference (i.e., with respect to a map-like representation of her environment).

The first notion seems equivalent to one of the two notions of 1PP discussed in the previous section. Consequently, there might be some contexts in which "self-location" and "1PP" refer to a single construct. However, forward proprioceptive drift, which is used in many studies on the FBI as an implicit measure of self-location, appears to be more related to the third notion. Indeed, this measure is obtained by moving participants around the room with a blindfold, and asking them to walk back to their original location. Presumably, this requires subjects to represent their current location and their original location within an allocentric frame of reference, compute a path from one to the other, and translate the relevant coordinates in an egocentric frame of reference to carry out the adequate movements.

By contrast, it is perhaps more difficult to say which notion of self-location is probed by the mental ball-dropping task, which is used as an alternative implicit measurement of self-location in horizontal versions of the full body illusion. This task involves asking subjects to imagine that they are dropping a ball from their location, and to estimate how long the ball would take to hit the floor, as a way to assess how elevated the subjects take their location to be compared to ground level. In so far as one normally drops a ball with one's hand – as opposed to one's mouth, for example – subjects might use the second notion of self-location as their reference point for the mental ball-dropping task. Furthermore, the computations required to perform the task might not require translation of the relevant coordinates (that of the ball and of the ground level) into an allocentric frame of reference. Indeed, subjects should be able to estimate the egocentric distances of the fictional ball and of the ground level with respect to the point of origin of their visuospatial perspective, and carry out the mental task entirely in an egocentric frame of reference.

Do you think these brief comments about the targets of the implicit measurements used in the Full Body Illusion literature are plausible and accurate? Specifically, do you think the proprioceptive drift task and the mental ball-dropping task measure the same notion of "self-location"? If not, do you have suggestions about how to disambiguate between different notions of self-location in empirical studies using the Full Body Illusion?

Yes, I would agree with your interpretation of the different definitions and measures of self-location. As mentioned above, in normal waking consciousness, the multisensory first-person perspective and self-location are typically co-located, and should also be comparable in the different implicit

and explicit measurements of self-location, even if they require, as you mention, different mental processing (note that in the walking task, memory processes might also play a more important role). However, it might well be that, if you modulate one or the other perspective, be it the visual, the auditory, or the gravitational, this would affect the different measures differently. One step in this direction would be to use different assessments of self-location measures in the full body and other illusions, and relate them also to the subjective perception during different illusions, which is something we have recently started in collaboration with Christophe Lopez (Nakul et al., 2020). As mentioned above, I am in general not yet very happy with the self-location measures we are using. More implicit measures such as place cell activity would be helpful.

Although the topic surrounding the self-awareness of animals remains beset with a number of difficulties, a few studies have demonstrated that non-human primates and mice may experience body ownership as well. These illusions similarly utilize multisensory stimulations akin to the rubber hand illusion in humans (i.e., (a)synchronous stimulation of a physical and artificial arm or tail). Do you think such bodily illusions can effectively translate to animal studies and validly allude to the presence of bodily self-consciousness in animals? What type of paradigm would you employ if you were to conduct such a study?

If you see how much difficulty healthy adult participants have in describing what exactly they feel during bodily illusions, I think it is very hard to imagine what animals would feel during such illusions and even harder to imagine how you would measure such or quantify these feelings. Nevertheless, as mentioned above, I think this literature is interesting and important for various reasons (e.g., the phenomenological control). If maybe not telling us much about bodily self-consciousness, animal studies might certainly help to shed light on basic underlying mechanisms, especially on multisensory weighing and integration. Next to the full body illusion in rats that I mentioned above, I would really love to do longer term experiments in, e.g., mice, if it is possible to do it in an ethically acceptable way, to better understand the plasticity of such multisensory integration mechanisms, which you cannot do in humans. What if a rat for example would, using binaural headphones, from birth on always hear from another rat's perspective (or from a stationary perspective in the room similar to (Mizumoto & Ishikawa, 2005)), while seeing and smelling from their own

perspective? How would that influence the rat's perceived self-location, as for example measured with a reaction to threat on various positions? Investigating such long-term multisensory mismatching stimulation would certainly tell us a lot about the plasticity of multisensory mechanisms underlying the bodily self.

Several influential theories presuppose that basic, largely implicit and pre-reflective bodily processes underlie self-consciousness, where the integration of sensory and motor bodily signals with the self as an agent of intentional object remains anchored in an embodied self (Blanke & Metzinger, 2009; S. Gallagher, 2005, 2013; Newen, 2018). On the contrary, opponents of this claim do not consider bodily sensations or components of bodily awareness (i.e., sense of ownership, self-location, and agency) a necessary prerequisite for self-conscious experience, or even an essential requirement for consciousness in general (Millière, 2020; Millière & Metzinger, 2020).

Cases from clinical samples encompass unique aberrations from ordinary bodily self-consciousness; for example, patients with asomatognosia suffer from an unawareness of ownership of a part of their body (loss of ownership), patients with tetraplegia experience paralysis that can result in the total loss of movement and sensation in all four limbs and torso (loss of agency), whereas out-of-body experiences from neurological origins include the feeling of disembodiment from one's own body and viewing it from an elevated visuospatial perspective (alterations of self-location). Individuals with body integrity dysphoria may not feel like a limb belongs to them and desire amputation or being paraplegic. Accumulating empirical evidence suggests that transient absence of bodily experiences or weakly embodied states are also encountered in non-clinical populations. Examples of such states include feelings of disembodiment or a detachment between the body and mental processes under the influence of psychedelic substances (Preller & Vollenweider, 2018; Timmermann et al., 2019; Vollenweider & Kometer, 2010) or a loss of spatiotemporal awareness in dreams (Occhionero & Cicogna, 2011).

Do you think that such experiences contradict the claims that purport a putative role of the body for self-consciousness? One might argue that even in the presence of loss of agency (e.g., tetraplegia), alterations of self-location (e.g., out-of-body experiences), or loss of self-location (reported in some drug-induced states, in sensory deprivation and in deaf blindness, (Millière, 2019)) one could nevertheless preserve a connection to a physical body and therefore to bodily self-consciousness. In the presence of "bodiless" dreams,

however, one may retain a sense of agency, self-location, and first-person perspective, despite lacking the experience of a body. Would it still make sense to strap such states to bodily self-consciousness, or would it be more appropriate to talk of perspectival consciousness?

I think that the mentioned examples do not contradict the claim of an important role of the body in self-consciousness for several reasons. First of all, I would argue that even if we find some rare instances (for example pathological or drug-induced) in which self-consciousness might be possible without momentary bodily experiences, it does not at all mean that bodily self-consciousness is not generally important in self-consciousness. There is the famous saying that the exception confirms the rule, and we know that the brain is highly plastic and adaptive, thus it is difficult to generalize from very specific cases to "normal" consciousness. Furthermore, all examples given are specific states in individuals who have or at least had experienced normal bodily self-awareness previously. For example, a patient with somatoparaphrenia might lose the sense of ownership for one hand but still has a normal sense of ownership for the other hand. A tetraplegic might still have a normal sense of agency over some body parts like the eye-lids. And a dreaming person senses her body in waking state. These instances might be an important prerequisite to be able to transiently perceive a "bodiless" state.

Thus, I would still see the lack of the sense of a body as a variation of an altered body perception. After all, even if you wanted to call it perspectival consciousness, a visual or auditory perspective is only experienced the way we experience it, due to the way our body is physically shaped.

> “ I would still see the lack of the body as a variation of an altered body perception ”

One can certainly argue that persons with surgical or congenital amputations retain a sense of bodily self-consciousness, despite the lack or loss of their limbs. In the most severe cases, individuals may physically comprise no more than their trunk and head. Yet, the fundamental sense of selfhood associated with bodily self-consciousness is ostensibly experienced as a global whole-body representation, rather than individual representation of separate body parts (Lenggenhager et al., 2007). In theory – and not considering the constraints of vital organs – how much of the body could we progressively

remove before the sense of (bodily) self-consciousness is lost? Along these lines, could prosthetics serve as a viable substitute for the physical body?

This is an intriguing question. Similar to the famous ship of Theseus example, which questions whether a ship would still be the same if all parts were successively replaced over time. This example would be even more interesting for a human being than for a ship, what if you replaced one organ/body part after the other in a human being, would she still be the same? While this remains thus far a thought experiment, the question on how self-consciousness is altered by, e.g., organ transplantation or prosthetics, is a very interesting and important one, which should be carefully investigated. I think the "problem" in your question might exactly be the "not considering the constraints of vital organs", as both empirical and theoretical evidence suggest that the trunk and head, where also the vital organs are located, is the core of this fundamental selfhood, which is also where people typically localize their "self" if forced to localized it in a single point (Alsmith & Longo, 2014). This also fits the idea that interoceptive cues, mainly from the trunk, might crucially underlie our sense of a bodily self (e.g., Park & Blanke, 2019). But in a pure thought experiment, my guess would be that as long as you have some physical body (even a prosthetic one if it were integrated in your sensorimotor loop) you would feel as physically embodied. And again, I would argue that there is an important difference between whether you previously had a body and lose/replace it as in your thought experiment, or whether there would be no body from the beginning.

Several clinical trials using psychedelic substances have evinced impressive and often persistent improvements in depression. During such sessions, perceived disembodiment or detachment from the physical body constitute common phenomenological experiences under the influence of psychedelic substances (Belser et al., 2017; Watts et al., 2017). In a separate line of research, an experimentally induced out-of-body illusion successfully alleviated symptoms in a number of chronic pain conditions, including fibromyalgia, endometriosis, chronic lower back pain, and spinal cord injury (Pamment & Aspell, 2017). Do you think that altered states of bodily self-consciousness, specifically those related to disembodiment, are central to the alleviation of symptoms in such conditions? If so, why and how would a perceived "detachment" from our bodies operate beneficially for our mental and physical health?

While the mentioned examples are very promising there is still limited empirical evidence. Replication studies are needed. However, I think that the experience of disembodiment, as well as possibly related sensations, such as the sense of lightness, might be beneficial. Again, I think it would be important to better quantify different phenomenological aspects of such altered sense of embodiment and to investigate in the different states (e.g., in virtual reality or during psychedelic drugs) to better understand which aspects of such experiences might be helpful. Generally, I am very excited by the idea that the unusual body experience itself rather than, for example, the pure neurochemical alterations due to psychedelic substances might cause some of these changes. If you think of the hyperembodiment model of Thomas Fuchs, for example (Fuchs & Schlimme, 2009), in which depression is suggested to be linked to a too rigid and strong sense of embodiment, it could well be that the sense of transient disembodiment or lightness might be helpful. Furthermore, while a constant sense of detachment from the body might not be beneficial, I think that there is a lot of therapeutic potential in using such tools to let people perceive how plastic the sense of the body actually is. This could also be applied in a more educative way by showing people that the sense of their own body might not be as rigid as they believe.

“While a constant sense of detachment from the body might not be beneficial, I think that there is a lot of therapeutic potential in using such tools to let people perceive how plastic the sense of the body actually is”

Virtual reality has undergone a transition from an expensive and arduous device to a functional technology that is increasingly employed both in empirical and home-use settings. While the immersive nature of virtual reality has already demonstrated considerable success as an application for behavioral health (e.g., exposure therapy for phobias or posttraumatic stress disorder) (Riva et al., 2018), a particularly auspicious feature of virtual reality involves the implementation of virtual avatars as bottom-up sensory modulators of existing body representations (embodied virtual reality). Virtual reality permits a degree of sensory control that would not be possible in physical reality, and thus facilitates unique opportunities to update aberrant representations of bodily self-consciousness.

With a potentially increasing recognition of embodiment in the convergence of phenomenology and pathology, do you consider embodied virtual reality a promising therapeutic tool for disorders of bodily self-consciousness? Is it or will it be possible to effectively "replace" our physical bodies with virtual selves? Given adequate sensory information, can we embody almost anything – e.g., an animal, a superhero, or an inanimate object such as a house? Along these lines, could we further embody multiple selves, and if so, how might this affect our sense of (bodily) self long term? Although the potential applications for clinical disorders seem promising, what are some of the ethical concerns and risks that need to be considered moving forward with virtual reality and other "body surrogates", such as robotics and prosthetics?

Yes, I definitely consider embodied virtual reality a promising therapeutic tool and potentially helpful for educational settings or training situations. We have recently shown that people can even feel like they are strongly embodying a grapefruit (Lesur, Aicher, et al., 2020). That's why I am optimistic that healthy participants can basically embody anything, at least as long as head-related visuo-motor coherency is given (Lesur et al., 2018b), even if it might be an alief rather than an illusion. While I have never tried to virtually embody several bodies and have a hard time imagining it, previous literature suggests it is possible (e.g., Heydrich et al., 2013). I agree with you that it is important to do more basic research before developing too many therapeutic applications, especially when it comes to children, who are presumably still developing their sense of a bodily self. I am surprised how little is known about how embodied virtual reality exposure alters (bodily) self-consciousness in children. It is one of my core objectives of my current Swiss National Science Foundation-funded project to investigate these mechanisms. It is important to carefully evaluate ethical considerations (e.g., Madary & Metzinger, 2016), especially as potential therapeutic embodied virtual reality, as well as embodied virtual reality for leisure (e.g., in games), will use much longer exposure times than what we typically use in the laboratory.

In the virtual reality literature, it is often claimed that good virtual reality technology should induce a "sense of presence", defined as the sense of being present within the virtual environment that one perceived through a head-mounted display (e.g., Heeter, 1992; Held & Durlach, 1992; Slater, 2009).

There are a number of technical specifications of virtual reality systems that appear to be strong mediators, if not requirements, for the induction of a sense of presence. These include, among others: stereoscopy (providing binocular depth cues), head tracking (providing action-contingent visual feedback), hand/body tracking (giving the user a virtual body), high screen refresh rate (enabling smooth visual motion), high screen resolution (providing clear visual input), and wide field of view (providing peripheral visual input). A meta-analysis of the relationship between the sense of presence (as measured by various questionnaires) and different technical specifications virtual reality systems in 83 studies found that head tracking was one of the most important features to induce a sense of presence (Cummings & Bailenson, 2016).

When these technical specifications are not met, the experience of virtual reality users can become quite uncomfortable. In particular, the lack of head tracking (or head tracking with high latency) causes a mismatch between visual input and proprioceptive/vestibular cues about self-motion, since the viewpoint rendered by the computer is not sensitive to the user's head movements. Such mismatch is often associated with an unpleasant combination of symptoms known as 'cybersickness' – a special case of motion sickness (Gallagher & Ferrè, 2018). There is some evidence that cybersickness is negatively correlated with scores on various presence questionnaires (Weech et al., 2019). This raises the following question: is the sense of presence in virtual reality really a positive experience that one has – in addition to whatever else one might experience while using virtual reality –, or is it simply the absence of the discomfort and abnormal sensations, such as cybersickness, associated with less sophisticated virtual reality systems? Do you think one of these two hypotheses is more plausible than the other, on the basis of evidence provided by your own research or virtual reality research at large?

I think it depends on the content of the virtual reality. If you imagine a virtual reality that exactly simulates reality, I would clearly expect that a strong sense of presence is just the absence of any discomfort and not per se a pleasant sensation. However, if you take virtual reality as a tool to let participants feel the sense of presence in a pleasant and surprising world that they otherwise could not be present, apart from maybe in dreams or during a psychedelic experience or similar, the mere sense of presence might be associated with a positive experience. But of course, depending on the content of the environment this could also rapidly turn into a nightmare.

If ethics, technology, and finances were no concern, what would be your dream research study?

Hmm, as you know I am a great fan of the virtual body swapping, as for example in the Machine To Be Another (Oliveira et al., 2016) and I love trying out all experiments as a participant before I start an experiment. My dream study would be to swap bodies in reality rather than in virtual reality. Maybe related to what was mentioned before, to create an experiment in which you could progressively swap out body parts and organs of the other person and test how it changes affective and cognitive processes, especially the sense of a bodily self and self-consciousness. If this answer is a bit too science-fictional, I would dream to do a study in humans as I suggested in animals above, letting them grow up with permanently altered multisensory perspectives or multisensory contingencies. If that sounds too scary, I would at least love to do more long-term exposure experiments. But even those need a lot of money and facilities. And there might of course still be ethical concerns.

With the rapid advancement of technology, what types of questions do you anticipate the field of bodily self-consciousness research will be attempting to answer in 20 years?

The question on how digitalization and digital interactions change bodily self-consciousness will be increasingly relevant. The fact that we interact more and more in quasi disembodied states through various digital media might shape the way we perceive ourselves and others. The fact that we might increasingly have the possibility to digitally change and represent certain aspects of our body and self in much more flexible ways (e.g., using facial filters, self-chosen avatars or holograms) might change our notion of self-consciousness and reveal new ethical questions.

“ The fact that we interact more and more in quasi-disembodied states through various digital media might shape the way we perceive ourselves and others. ”

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