

**Where are you?**  
**Self- and body part localization using virtual  
reality setups**

Dissertation

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# 1. General introduction

This thesis investigates where it is that people locate themselves in their bodies. Typically, when someone is asked where he<sup>1</sup> is, he identifies the location of his body as where he is located. Assuming asking where someone is, is indeed posing a question after the location in space of the material object constituting him, this answer is a perfectly correct one. However, as human bodies are extended in space, the answer may possibly be further specified. By asking a more specific question, possibly a more specific answer will be provided. Is/are there one or more specific region(s) of their bodies people consider themselves to be most? Or—in slightly different words—is/are there one or more region(s) of their bodies people associate themselves with specifically? The answer to this question is not currently known. Therefore, it is this question after (a) more specific self-location(s) in the human body that is investigated in this thesis, by means of different behavioral tasks in a series of related experiments using virtual reality (VR) setups. Furthermore, it is investigated how accurately people can locate several of their body parts, when using VR setups. This provides the additional possibility to examine indicated self-locations not only in terms of the physical body, but also in terms of what I call the perceived body (the perceived body will be introduced further in section 9).

In the sections following this general introduction, first some background will be provided on the position of the topic of self-location within the cognitive science and neuroscience literature on the bodily self (section 2). This will be followed by some background on where the topic of the bodily self fits in the philosophical literature on (self-)consciousness (section 3). These positioning efforts will not be comprehensive, as the relevant literature in both fields is much too extensive for providing such here. They are mainly there to show the most important connections of the current work with the existing literature on the bodily self. After having provided this wider framework, a section (4) will follow discussing previous work that has experimentally studied self-location, focusing on tasks probing the specific part(s) of the body people locate themselves in. This will be followed by a discussion of the motivations for performing the current series of experiments using various VR setups (section 5). Then the first-person perspective (1PP) pointing paradigm will be introduced which was used in the current experiments for both self- and body part localization using VR setups, as well as the third-person perspective (3PP) pointing to self on a body template task which was performed outside of VR (section 6). Then an overview of the first of the three current experimental studies will be provided (section 7). In this study, participants were asked to point directly to themselves with a virtual pointer while wearing a VR headset, as well as to point directly to themselves outside of VR on an outline of a human body under the assumption it was depicting them. As a VR pointing to body parts task was included in the second study of this thesis, section 8 will then discuss several tasks testing how accurately people can indicate the locations of their body parts. In the second study (introduced in section 9), participants were

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<sup>1</sup> In cases without a specified referent, male pronouns are to be read as referring to all sexes or genders.

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asked to point directly to themselves with a virtual pointer, as well as to several of their body parts, in two different VR setups, i.e. a VR headset and a large-screen immersive display (LSID). As a self-avatar was implemented in study three, section 10 will introduce the use of VR self-avatars in relevant research and applications. In the third study (introduced in section 11), participants pointed directly to themselves and to their body parts with a virtual pointer while wearing a VR headset, before and after having had a self-avatar adaptation phase, experienced from two different viewpoints on the body, i.e. at eye- and at chest-height. How the experiments for this thesis were performed and why they were designed as they were, will be explained in the three specific introductory sections (7, 9 and 11). Section 12 contains the general conclusions and an overall discussion of the thesis as a whole. Then the three original research papers will follow, with only formatting changes and incidental corrections in language relative to the published article versions: article 1: Van der Veer, Alsmith, Longo, Wong & Mohler (2018); article 2: Van der Veer, Longo, Alsmith, Wong, & Mohler (2019); and article 3: Van der Veer, Alsmith et al. (2019).

## 2. Self-location and the bodily self in the cognitive and neurosciences

This section will briefly provide some background on the topic of self-location from the cognitive science and neuroscience literature on the bodily self. The next section will then provide a wider framework to this topic by discussing the bodily self from the philosophical literature on (self-)consciousness. Specific experimental studies on (global) self-localization and self-localization within one's body will then be discussed in section 4. section 8 is where previous experimental work on body part localization will be presented, which becomes relevant from the second study on.

As Blanke (2012) states, "Human adults experience a 'real me' that 'resides' in 'my' body and is the subject (or 'I') of experience and thought." In this statement he connects the experienced me, with my body, as well as with the experiencing I, and thereby self-consciousness with the body and consciousness per se. What I would like to take from this, is that there thus seems to be a link between my experience of what I typically refer to with the terms 'I', 'me', 'myself', or 'my self'<sup>2</sup> and my body. This and similar ideas have, particularly in the last two decades, led to a blooming field of experimental work into the so-called bodily self and bodily self-consciousness.

Bodily self-consciousness is typically defined as the non-conceptual and pre-reflective representation of body-related information (Lenggenhager, Tadi, Metzinger & Blanke, 2007). Often, three components of bodily self-consciousness are discerned: self-identification or body ownership, self-location, and first-person perspective (1PP). Body ownership concerns the conscious experience of identifying with or owning a body; self-location the experience of where 'I' am in space, or, more bodily, of being a body with a given location within the environment; and 1PP the experience of the position from where 'I' perceive the world, or, again more bodily, of taking a first-person, body-centered, outlook on an environment (Blanke, 2012). For a good recent overview of the scientific work on the functional, computational and neural aspects of bodily self-consciousness, see Blanke, Slater & Serino (2015).

In clinical cases of patients reporting different types of autoscopic experiences (mainly linked to lesions centered on the temporo-parietal junction (TPJ)), different aspects of bodily self-consciousness (body ownership, self-location and 1PP) can come apart (Blanke, 2008; Blanke & Metzinger, 2009). In autoscopic hallucination you see your body in extracorporeal space (as a double), from the usual 1PP anchored to your physical body and without disembodiment of your physical body (i.e. your experienced self-location is in your physical body). In heautosopic hallucination you see your body alternatingly from the usual 1PP in your physical body (like in autoscopia) and from an extracorporeal perspective. Self-location is often experienced as ambiguous, or as alternating between the physical body and the double.

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<sup>2</sup> I will use these terms interchangeably in the context of self-location, as the versions of different person and number will be. In this context, I consider the main differences between them of mere syntactical nature.

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In heautoscopy, experiences of bi-location can occur, such that self-location and the origin of the 1PP are simultaneously experienced in different positions. Body ownership can be experienced over the double, your physical body, both (simultaneously or alternately), or be unclear. Heautoscopy forms an intermediate between autoscopia and out-of-body experience (OBE). In an OBE you experience yourself as located outside of your body (disembodiment), while you typically see your body and the world from an extracorporeal perspective above yourself (a form of autoscopia). In an OBE, body ownership, self-location, and 1PP are all abnormal, but typically do not come apart; ownership is over the virtual body, from where you see your body and wherein you experience yourself to be located. There are some reports of OBEs, induced by electrically stimulating the TPJ in patients, with disembodiment but not autoscopia, indicating that self-location and 1PP can also come apart there and may have (partially) different neural underpinnings (De Ridder, Van Laere, Dupont, Menovsky & Van de Heyning, 2007). In autoscopia body ownership, self-location, and the origin of the 1PP (but not the perspective on your body) are as normal; in heautoscopy they can all three be abnormal *and* need not be spatially consistent; in a typical OBE they are all three abnormal, while being spatially consistent with each other. For a discussion of disturbances of bodily awareness with a focus on disturbances of body part awareness and localization, see section 8.1.

Experimental work on bodily self-consciousness has been strongly promoted by advances in VR and related technologies, making it possible to provide ambiguous multisensory cues concerning body ownership, self-location, and 1PP in healthy participants (Blanke, 2012). Some of these experimental findings will be discussed in section 4.1 on global self-localization. Overall, and largely in line with patient studies, experimental studies have provided more extensive back-up for the functional and neuro-anatomical dissociation of ownership from self-location and 1PP, than of self-location and 1PP (Blanke, 2012; Serino et al., 2013). Regarding 1PP, a further fruitful differentiation can be made into egocenter, origin, and egomotion (Alsmith, 2014). Egocenter is then the center of an egocentric frame of reference, centered on the body and used to locate external objects relative to you. This apparently simple phenomenon may in fact be quite complex. Neurophysiological and neuropsychological research on spatial representation suggests independent motivations for the head (e.g., Avillac, Denève, Olivier, Pouget & Duhamel, 2005; Grubb & Reed, 2002) and the torso (e.g., Karnath, Schenkel & Fischer, 1991) grounding the relevant frame of reference. Origin can be understood as the origin of a sensory field, from where you experience the world; which I will call viewpoint. Egomotion concerns the flow of your sensory experience, such that you can see where you are headed when moving.

The aspect of the bodily self of specific interest in this thesis is that of self-location. In the context of the bodily self, self-location is typically described in *global* terms, as the location where 'I' am in space, of being a body with a given location within the environment (Blanke, 2012), or as the experience of occupying a determinate location that may or may not be coinciding with one's own body (Lenggenhager et al., 2009). The question under investigation

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in this thesis is rather where it is that people locate themselves *specifically* within their bodies, or, slightly different, the part(s) of their bodies people associate themselves with the most. This question is still about self-localization in space and in bodily terms<sup>3</sup>, but forms a specified version of the more global examples of self-location just given. The main interest here is to find out whether people locate themselves equally spread out over their bodies, or rather in one or more specific regions of their bodies, and if the latter, which one(s). section 4 will discuss some well-known examples of studies of self-location of the typical, global kind, followed by summaries of the rarer type of self-localization studies trying to specify self-location(s) within the body.

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<sup>3</sup> This also means that the location(s) under investigation here are not of an immaterial self or a self separate from the body (not withstanding possibilities like selves extending into peripersonal space, tools, or towards or into other bodies of different kinds).