On Eliciting a Sense of Self when Integrating with Computers

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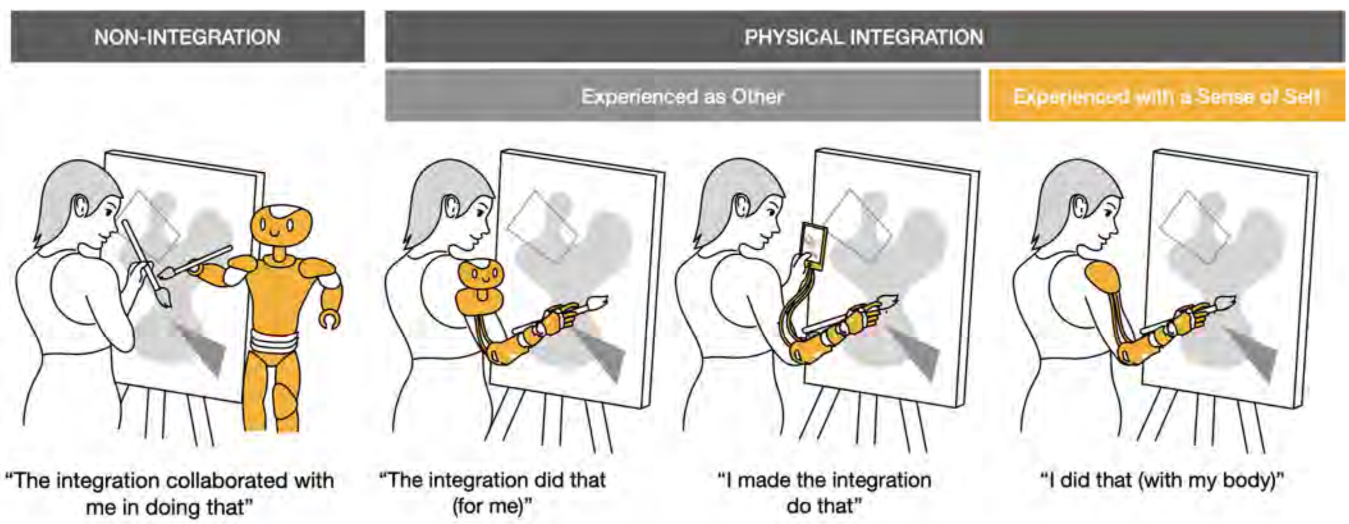

Figure 1: We argue that eliciting a sense of self allows for user experiences such as "I did that (with my body)", going beyond "I made the machine do that (for me)" and "The machine did that (for me)", which is often the current approach when it comes to physical integration of computer systems.

ABSTRACT

While some Human-Computer Integration (HInt) systems have successfully demonstrated that humans and technology can be physically and functionally integrated, we find that these integrations are not necessarily part of the users identity (i.e. self-judgment) or felt as part the user (i.e. with a sense of self) and that they can even create feelings of self-dissociation. Literature on how to elicit these self-experiences is often inconsistent and vague, which complicates the metric for success and hinders the advancement of research. To help designers elicit and systematically evaluate *in particular a sense of self*, we draw metrics and theory from phenomenology and cognitive science. We find that experiential structures such as "pre-reflective experience", "sense of body-ownership" and "sense of agency" are to be designed for as they together seem to elicit a "sense of self".

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CCS CONCEPTS

• **Human-centered computing → Interaction paradigms**; **HCI theory, concepts and models**.

KEYWORDS

human-computer integration, human augmentation, experiential integration, sense of self, cognitive science, phenomenology

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1 INTRODUCTION

Recent Human-Computer Interaction (HCI) research has highlighted a new paradigm that moves from a traditional command-response interaction towards an “integration” of technology with the human body. Instead of considering human and computer as two separate entities, the research area of Human-Computer Integration (HInt) with its subsection “fusion” aims at integrating computers with users into “one human-technology assemblage” to enhance human’s capabilities [3, 21, 62, 66]. This goal includes integration on multiple levels: (1) *physical integration* where a technology is either placed inside or on the body [62], (2) *functional integration* where a technology take part in a cognitive function to either assist or restore that function, or (3) experiential integration where a technology becomes part of the users *reflective* (i.e. explicit) experience or *pre-reflective* (i.e. implicit) experience of (a) themselves (self-experience) and/or (b) the world (world-experience) by being felt in a certain way.

Research has shown that physical or functional integration of a technology does not necessarily lead to an experiential integration [29, 37, 63, 82]. In particular, it is found that technology is typically experienced as something “other” in the sense that either feels completely autonomous (“the integration did that (for me)”) or is reflectively controlled by the user (“I made the integration do that”) [8], which is associated with traditional command-response type interactions. Going beyond these experiences, researchers are now interested in how integrated systems could be associated with users’ self-experience to elicit statements such as “I did that (with my body)” (Fig. 1) [20, 37, 62]. As we will argue, this step requires us to go beyond thinking about self-experience as only reflective *self-judgments* (“I did that with what I think is my body”) but also as a pre-reflective *sense of self* (“I did that with what feels is my body”). The difference between the two will be further expanded upon in section 3).

The elicitation of a pre-reflective sense of self is important, as physical and cognitive integration systems without a sense of self have been shown in some cases to create unpleasant, disembodied, or dissociative experiences, despite being able to increase functionality and performance [5, 37, 61, 63, 82]. For example, researchers found that systems where participants’ hands are controlled by a computer through electrical muscle stimulation (EMS) are often experienced by users as “scary”, and feeling as if they are being “pushed by someone” or “being hacked” [61, 82]. Similarly, interviews with prosthetic and brain-implant users reveal that some experience their prosthesis or integration as a foreign object rather than a part of themselves — even when they are successful users [28, 29, 63]. The users would often report that the prosthesis is “in the way” or being unavailable, requiring too much effort to use, ultimately resulting in abandonment of the technology or users being less protective of it [17, 63]. Researchers argue that eliciting a sense of self could eliminate such disruptive experiences and lead to improvements in protective behavior [17], availability expectations [26, 27, 63], and help avoid unwanted self-dissociation among users [5, 29, 37] (see Fig. 2).

These issues will increasingly become critical, as we see more research towards said “invasive” technologies such as supernumerary robots [45, 67, 68, 90, 91], neuromuscular interventions [37, 51–53, 82], and or implants [40]. For such systems to be engineered for successfully integrating with a user’s self-experience, a formalized evaluation metric both in terms of its performance and experience should be adopted, and further discussion on how these factors are considered in the process of designing such systems are necessary. However, there is currently no consensus among HInt researchers as to what it means for a technology to integrated with a user’s “self-experience”, and how one could design for such experiential integration [62]. Further, we note that the term self or self-experience in HInt research is often left undefined, used vaguely, or inconsistently [6, 46, 62]. This complicates the metric for success, which hinders the advancement of HInt research on self-experience and development of practical applications.

Based on research in phenomenology and cognitive science, we find that self-experience consists of multiple levels of abstraction that are either (1) *self-judgments* or (2) *a sense of self.* Self-judgments are one’s reflective experience of oneself that depends on one’s own conceptual understanding of their body, thoughts, and values and relies on memory [14, 23, 27], while a sense of self is the pre-reflective “sense of mineness” or experiential self-reference one has inherent in any form of conscious state [14, 92]. Contrary to self-judgments, sense of self is not experienced through self-reflection but is rather independent of the possession of linguistic and conceptual abilities. Its absence can be found in some individuals with schizophrenia spectrum disorder [69, 70]. Further, it is often argued that sense of self can be broken into “sense of body-ownership” and “sense of agency” [14, 27, 61, 83, 92]. By being pre-reflective, these “senses” are often characterized as having a “thin” phenomenology [58], that is, they are not experienced as an explicit or reflective cognition (unlike self-judgments), instead, they are characterized by a very brief and minimal “pre-reflective” (conscious, but outside our attention) awareness [14, 27, 83]. For both sense of self, sense of body-ownership, and sense of agency, we use the term “sense” to be consistent with popular literature where “sense” is often used to denote minimally (implicitly) conscious feelings (e.g. as in “sense of body-ownership” and “sense of agency”) which one can feel without being explicitly aware of it [27, 79, 83, 92]. Further, following [14] we define the term “feeling” as anything that shows up to the mind in conscious experience, be it a visual object, intuition, gut feelings, etc. To exemplify the difference between reflective self-judgments and pre-reflective sense of self, prior work has referred to phantom limb patients who reflectively know and judge that they are missing a limb but pre-reflectively still feel the presence of a non-existing limb “as if it’s still there” [63]. In the first case the self-experience is based on reflective self-perceptions, knowledge and inferences, whereas the second is based on pre-reflective *feelings* about what constitutes their body.

We note that researchers in HCI have mostly focused so far on users’ self-judgments when it comes to integration systems, helping us to understand how users with integrations reflectively think about themselves (also referred to as “body-image” [45, 46], “self-image” [12], “self-perception”, and “relational self” [62]), and used reflective evaluation methods that rely on users’ self-judgments [4, 15, 31, 35, 40–42, 74, 77, 85, 88] while overlooking the pre-reflective

Figure 2: Beyond the mere experience of feeling as one with a technology, eliciting a sense of self over a technology can also have positive behavioral implications on a user.

aspects of experience [25, 26, 43, 47]. We argue that designers are well advised to consider both self-judgments and sense of self when thinking about human-computer integration technology and self-experience. Making this distinction enables more precise research, novel opportunities, and, as we will argue, increases the likelihood for success.

The structure of the paper is as follows: in section 2, we discuss phenomenological and neuroscientific theories of awareness. In section 3, we compare the impact of types of awareness on self-experience with HInt research to help us articulate the gap in vocabulary and design knowledge around experiential perspectives of selfhood in integrated systems. We argue that in order to close this gap, it can be useful to look at not only reflective but also pre-reflective aspects of self-experience, in particular sense of self and its components sense of body-ownership and sense of agency. In section 4, we highlight how to engage not only with self-judgments, but also the sense of self, as well as how one can design to elicit and evaluate a sense of self over an integration. As we show in section 5, since these senses are inherently pre-reflective, widely used self-assessment methods that evaluate reflective experience do not necessarily measure a sense of self, meaning that designers and researchers miss out on opportunities of eliciting a sense of self in their design. We discuss in section 6 what this means for HCI work on self-experience and conclude with limitations and opportunities around eliciting a sense of self when integrating with computers.

This article makes the following contributions:

- It introduces concepts of reflective and pre-reflective awareness from phenomenology and cognitive science and highlights their influence on self-experience, as we believe the vocabulary helps academics and educators discuss the differences in experiential integration of self with HInt systems.
- It provides researchers with an understanding of the two types of self-experience (1) reflective self-judgments and (2) pre-reflective sense of self caused by reflective and pre-reflective awareness, and show the benefits and limitations of each type of self-experience in design and evaluations of HInt systems.
- It argues that researchers primarily design for self-judgments rather than sense of self due to methodological limitations, and guides designers on how to go beyond self-judgments to facilitate a sense of self over an integration by using methods to elicit a sense of body-ownership and sense of agency.
- It provides researchers with a method to evaluate pre-reflective aspects of experience such as a sense of self using phenomenological interviews and phenomenological mixed methods.

2 TWO KINDS OF AWARENESS: REFLECTIVE AND PRE-REFLECTIVE

Before discussing self-experience, it is important to note that it depends on the two possible modes of awareness according to emergent phenomenological and neurocognitive models of consciousness: pre-reflective (implicit) self-awareness and reflective (explicit) self-awareness. [9, 14, 27, 43, 49, 92]. In the context of bodily control, reflective awareness enables higher degrees of control and perceptual detail through continuous monitoring, while pre-reflective awareness enables implicit control through feeling that the body is there doing what it is supposed to without demanding full attention (Fig. 3). These two types of awareness become a key to understanding the two notions of self-experience: *self-judgments* and *sense of self*, discussed in section 3.

2.1 Reflective Awareness

Reflective awareness is the structure that, through attention, concentrates or focalizes the appearance of things in our immediate experience [27, 43]. To be experiencing is always to be experiencing 'something'; as Gallagher and Zahavi write: "[A]ll consciousness (all perceptions, memories, imaginings, judgments, etc.) is about or

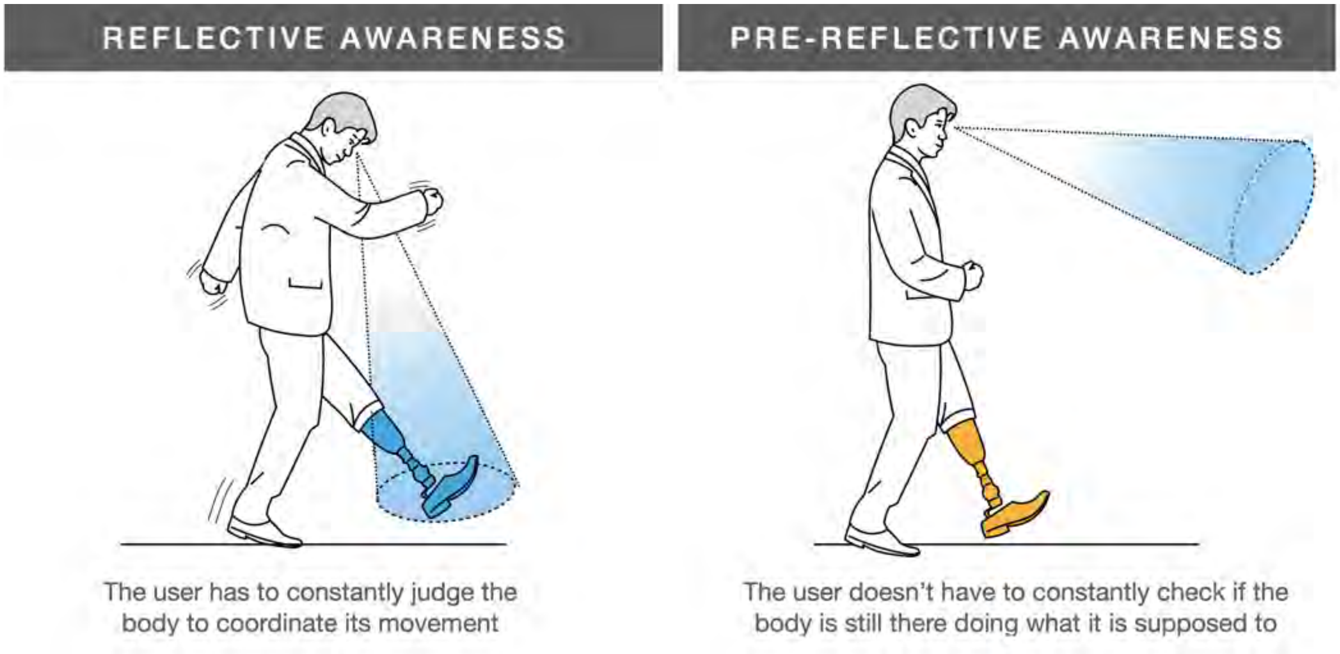

Figure 3: Reflective and pre-reflective awareness modulates conscious experience of our bodies in various ways.

of something" [27]. If you are an *unskilled* walker, you might be reflectively monitoring your footsteps as you are walking up a set of stairs, or if you are a *skilled* walker, you might *not* be reflectively monitoring your footsteps, but rather, reflectively focus on something else that is important to you, e.g. what to say to your friend at the end of stairs, or what you will do later in the day. In this way, reflective awareness generates experiences with higher detail that allows for increased precision (e.g. more precise movements, thoughts, planning, etc.). Objects that are reflectively experienced seem to exhibit a richer phenomenology than things not reflected upon [10, 49]. In this way, thinking about something or making a judgment is experienced with a reflective awareness that enables the brain to **allocate cognitive resources towards the most important things in the environment, resolve ambiguities, and present stimuli in high detail** [7, 11, 14].

2.2 Pre-reflective Awareness.

Pre-reflective awareness is a "thin" phenomenology that is a constant *minimal* structural feature of conscious experience [27] and includes transient senses like a sense of self [14, 83]. For example, when reading a text, one is attentive to and reflectively engaged with the contents of the text. But while focusing on the text, one still implicitly experiences simple gists such as shapes and colors in one's peripheral vision [84], or, at the same time, implicitly feel the sensations of one's foot touching the floor, or, at the same time, implicitly feel a weak gut reaction or intuition towards the contents of the text.

Taking the previous example, when climbing a flight of stairs, one often does so without monitoring and planning every movement of one's body. We generally (unless we have had an injury and need to re-learn how to walk up stairs) do not need to pay explicit attention to our every step to coordinate our movements. Instead, we are able to coordinate our body to enable particular movements all while we can focus on other things (see fig. 3) [18]. As Gallagher and Zahavi puts it:

> "Our attention, [or] our intentional focus is normally on the task to be performed, the project to be accomplished, or on some worldly event that seems relevant to our action. Our attention is not on our bodily movement [or thoughts]." [27]

In this way, one's pre-reflective awareness enables bodily movement without reflection, and, unlike automatic body reflexes which are felt as outside our control, pre-reflective awareness of the body also ***consists of an implicit experience that our body and thoughts are ours and that their movements are initiated by us***[27].

2.3 The Dynamic Interaction between Reflective and Pre-reflective Awareness

One feature of our body being pre-reflectively felt, is that we can easily seek out different parts of our pre-reflective feelings of our body and thoughts and bring them into our reflective awareness [26]. As such, we are able to shift a pre-reflective "sense" into a reflective "judgment" and inspect, understand and take action in detail [24]. For instance, being able to feel my foot pre-reflectively allows me to know that it is there, and, if I see so necessary or if things feel off, I can *reflectively* check up on it and make sure that it is doing what it is supposed to.

The benefit of being able to shift between a pre-reflective and reflective awareness is in part due to the additional details that reflective awareness can enable, or the lesser need for continuous monitoring and control that pre-reflective awareness can enable. Whereas senses in our pre-reflective awareness might consist of rough "gists" of stimuli, reflective awareness enables us, if any pre-reflectively experienced stimuli proves interesting or suddenly becomes strong (e.g. a gut feeling), to bring them into focal attention and experience them in high detail [14, 27]. Further, while one can only be reflectively aware of a few things at the same time, pre-reflective awareness enables us to be aware of multiple stimuli at the same time [27, 49]. Lastly, it seems that for some integrations the need for reflective awareness decreases over time with the integration becoming more pre-reflectively experienced. For instance, some prosthetic users report that their need for explicit awareness of what their prosthesis is doing "decreased over the years" resulting in a lesser kind of awareness [63]. Thus, it seems that using an integration over longer periods of time can assist an integration towards becoming pre-reflectively experienced.

HInt researchers could take advantage of reflective and pre-reflective awareness by designing devices that allow for both. For example, while a reflective awareness of a prosthetic limb, an exoskeleton, or a robot arm could enable fine and precise control over movements, designing a system that only relies on reflective awareness would limit the user's attention to focus on controlling just that integration. In contrast, an integration that is also pre-reflectively experienced would while enabling control (although not as detailed) and implicit awareness of what the integration is doing also free up cognitive resources for the user to reflectively focus on other things than what their integration is doing (fig. 3). Further, it seems that many integrations want to move from reflective to pre-reflective experience over time. Learning to play an instrument is, for instance, very reflective at first but becomes pre-reflective with practice. Same is true for climbing a set of stairs, riding a bike, etc. There are therefore disadvantages to systems that never move from reflective to pre-reflective experience as such systems would need users to constantly monitor their devices reflectively in order to use them. Because of this, we urge researchers to consider reflective and pre-reflective processes of experience and ways for implementing them in their designs.

Further, we argue that knowing about this distinction between reflective and pre-reflective awareness can help to more systematically design a device that aims to be experienced as part of the user. For instance, such knowledge could help to more precisely understand how a person experiences their prosthesis [63] and help designers figure out ways to enable pre-reflective control and sense of self over such prostheses. As self-judgments and sense of self relate to different kinds of awareness, reflective and pre-reflective self-awareness can help us distinguish more clearly between these two different notions of self-experience and how they bring about different approaches and advantages in terms of integrating with technology. We will discuss the implications of reflective and pre-reflective awareness in section 3.

3 DEMYSTIFYING SELF-EXPERIENCE: JUDGMENTS OF SELF AND SENSE OF SELF

The definitions of "selfhood" or "self" and how the terms are used vary strongly across disciplines: in contemporary phenomenology selfhood refers to how one experiences oneself, while in neuroscience selfhood refers to how the brain biologically represents the body. Within both of these fields, many terms have been used to describe selfhood with multiple meanings such as self-image" [23], "narrative self" [27, 92], "relational self" [2, 62], "autobiographical self" [13, 14], "neural self", "self-representation", "embodiment", and more. As has been argued by many researchers before us, while selfhood might be represented in neural structures of the brain, we know about it primarily through experience [14, 17, 27]. In such case, we argue that it is helpful to distinguish between pre-reflective and reflective awareness for HInt system design as it can help us to categorize and reduce previous notions of self-experience into two different experiences: (1) a pre-reflective sense of self [14, 27, 76, 92] and (2) a reflective self-judgment [14, 23, 92]. To make the experiential difference between these two kinds of selves explicit, **we use the term "self-judgment" to clarify that the self-experience is about the reflective type of self-experience and "sense of self" to clarify that it is about the pre-reflective type of self-experience** (see fig. 4).

To illustrate the difference between self-judgments and sense of self, imagine for instance wearing a pair of shoes so much that you start describe them as an "extension of your feet". In this case, these descriptions could simply mean that you perceive them as part of your identity, that is, how you conceptually understand or like to describe yourself. Perhaps since you always wear the shoes, you compare them to being similar to your feet which are also always there. However, conceptually describing yourself in a particular way does not necessarily mean that you feel your shoes in the same way as your feet or other body parts, i.e. with a sense of self. Since the two kinds of self-experience (self-judgments and sense of self), have different structures and outcomes, they require different design and evaluation methods, which we will discuss in the following sections (section 4 and 5. In this section we will expand on the differences between the two types of self-experience, and their design implications and limitations.

3.1 Judgments of Self

Judgments of Self or *self-judgments* (also labeled as "self-image" [23], "narrative self" [27, 92], "relational self" [2, 62], and "autobiographical self" [13, 14]) is the perceptual, emotional, and conceptual interpretation of oneself based on one's past experiences — regardless of how oneself actually looks, behaves, thinks, or is [23, 27]. This self-experience happens when we become reflectively aware of ourselves, it grows with our life experience, and depends on distributed networks of the brain and working memory (fig. 4) [14]. Throughout our lives, we judge ourselves and get judged by others. This helps us form certain understandings of who we are, what we look like, what values we have, and so on. These understandings surface when we reflect upon ourselves and help us form an identity or self-narrative. In this way, based on people's personal experiences, one's self-judgment can vary greatly between individuals and their individual capacity or desires to conceptualize and form narratives about themselves. Further, as they depend on people's ability and willingness to self-conceptualize, self-judgments can be inaccurate with regards persons actual capabilities, appearance, dispositions, and so on.

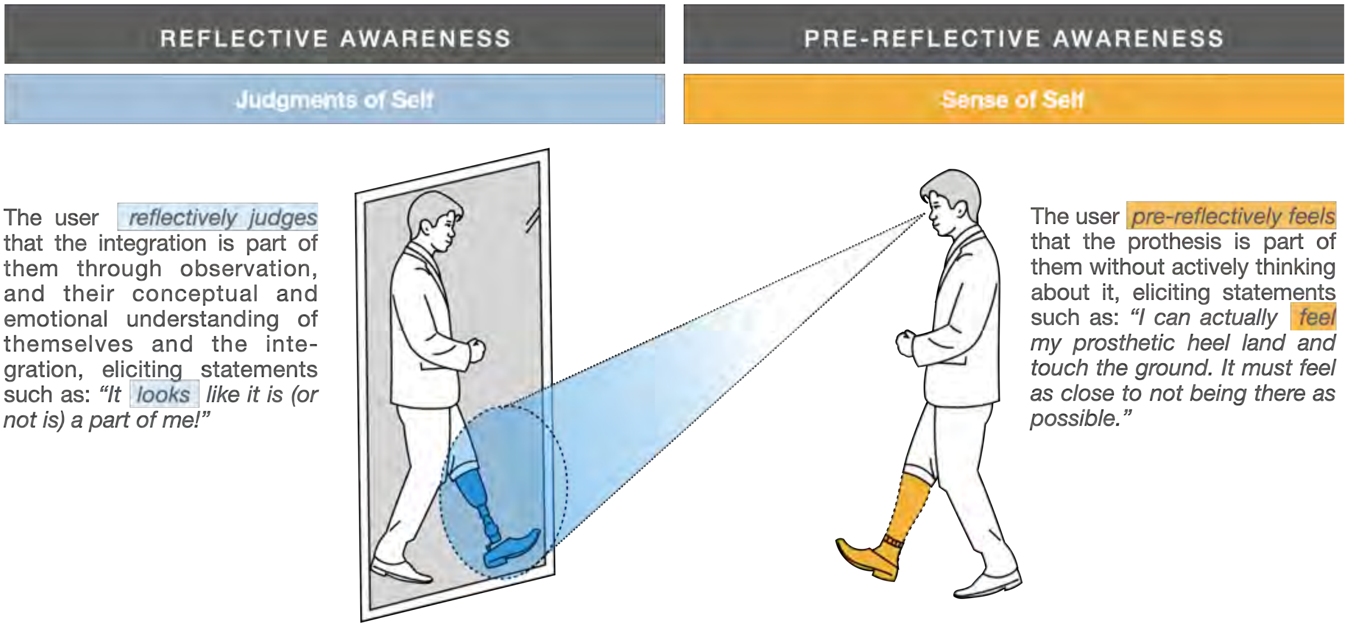

Figure 4: Reflective and pre-reflective awareness of ourselves modulates self-experience in various ways.

Design Implications of Self-judgments. There can be many reasons for HCI researchers to create technology that impacts self-judgments (and not necessarily sense of self). Misjudgments of the self are common in the general population, for instance in eating disorders such as body dysmorphic disorder, anorexia nervosa, and bulimia nervosa. Together with self-judgments about one's appearance such as one's race or body shape, misjudgments or negative self-judgments can be unpleasant and influence one's self-esteem, mood, social functioning, and occupational functioning [34]. In such cases, researchers might want to design integrations that alter self-judgments to improve self-esteem and wellbeing. Therefore, integration systems that target users' self-judgments, have the capacity to influence users' conceptual, emotional and reflectively perceptual self-understanding, which in turn can affect their self-esteem, identity, social functioning, and ability to coordinate and plan.

Prior work has examined the potential of devices to change users' self-judgment. For example, Tajadura-Jiménez et al. [80, 81] built a device that changes the sound frequency of participants' footsteps to make users perceive themselves as lighter or heavier. Shifting the sound of the footsteps to lower frequencies resulted in subjects describing their body as weighing more, while higher frequencies resulted in users describing their body as weighing less. As another example, Li et al. [48], developed an ingestible sensor that measures body temperature throughout the user's digestive system and delivers the feedback through a waist belt equipped with heating pads. After experiencing the ingestible sensor and heating pad, users reported that the technology let them know more about their body which in turn lead to different conceptualizations of themselves. This exemplifies how having greater access to information about oneself can alter one's conceptual understanding of oneself which in turn leads to new or different kinds of self-judgments, e.g. by understanding how one's body works and reflecting on what a bodily sensations might mean. Additionally, researchers might also want to target self-judgments to help users more easily transition during a sudden change in physical appearance. For instance, by building a facial prosthetic that gradually disappears, researchers can help burn victims adjust and learn to accept their scars by gradually changing their idea of what they are supposed to look like to include their new appearance.

Limitations of Self-judgments. While it can be beneficial to design technologies that modify a user's self-judgment, doing does not necessarily elicit a sense of self. Take for example phantom limb patients, who reflectively know that they don't have their limb anymore but still pre-reflectively feel that there is a limb present. Or somatoparaphrenia patients, who reflectively know that the limb attached to them is theirs but still pre-reflectively feel that it is not a part of them. In order to design an integration that truly becomes part of the user's self-experience (both self-judgments and sense of self), it is not sufficient to simply design for a user's reflective self-judgment only. Rather, one must also consider ways in which the integrations can elicit a pre-reflective sense of self.

3.2 Sense of Self

Sense of Self (also labeled as "core self" [13, 14], "experiential self", or "minimal self" [27, 92]) is a pre-reflective sense — which often goes unnoticed — that the body moving or the thoughts formed in one's mind are one's own (and not anyone else's) [27]: A sense of self references to the individual organism in which events are happening that the events are happening to them [14]. Lately, the sense of self has received attention from philosophers and cognitive scientists [13, 14, 83, 86], where distortions in the sense of self have been linked to disorders like schizophrenia and depersonalization

[75, 76]. Similarly, some integration systems like brain-computer interfaces have also been shown to distort the sense of self of some users [28, 29]. Being able to elicit a sense of self of an integration would allow researchers to create technology that is non-disruptive and feels like a part of the user.

Design Implications of Sense of Self. There are many reasons why researchers might want to investigate ways in which a technology can elicit a sense of self. As discussed earlier, eliciting a sense of self over a technology can lead to positive behavioral implications such as greater protective behavior, expectations of availability, and feeling present and empowered rather than self-dissociation (see fig. 2). Prior work has examined the potential of devices to elicit a sense of self over an integration. For example, Kasahara et al. [37] investigated practical measures with which a diminished sense of self could be avoided when using electric muscle stimulation. By knowing the intent of the user and stimulating their hand within a certain time window, they demonstrated how to sustain the users sense of self by having users not feel as if someone else initiated their hand movements. In another example, Nishida et al. [65] built an exoskeleton that minimizes the user's grasp to that of a child. Using this device, questionnaire reports revealed that users felt their hand to be smaller, and that they, when asked to design toys for children, had a better first-person understanding of how a child might experience their toy design. Further, Saraiji et al [74] examined whether a sense of self could be elicited over a supernumerary robot arm to augment their bodily capabilities. In a fixed questionnaire of 12 users, they found a significant increase in feeling that the robot arm is part of the users' body over a few sessions [74].

Limitations of Sense of Self. Some of the main limitations of eliciting a sense of self when integrating with technology consist of design and evaluation methods enabling researchers to reliably elicit and distinguish between self-judgments and sense of self in integration systems. For example, if a user is asked to state whether a third robotic arm or sixth finger is felt with a sense of self, the user might hesitate to answer and begin to reflect on it. Because of this reflection, the user's answer would be influenced by their personal judgments of what it means for something "to be felt with a sense of self" which, again, would be biased by their past experiences, prior knowledge, or conceptual understandings. For instance, some users might think that a sense of self means that the robot hand or finger looks like their own hand; or some users might even post-hoc convince themselves that they felt something and fabricate stories that do not accurately represent the true experience of the integration (see more in section 5). Because of the reflective awareness being possibly involved in a user's self-judgment, evaluating if a technology is experienced with a sense of self cannot be accurately determined by simply asking the user if they feel that technology is part of them and taking their response directly at face value (although this is typically done by many researchers). Instead, evaluating sense of self as a pre-reflective aspect of self-experience requires methodologies like phenomenological interviews that do not rely on reflective self-judgments (see section 5).

4 DESIGNING FOR ELICITING A SENSE OF SELF

So far, we have discussed the different structures of self-experience, in particular reflective and pre-reflective awareness and the associated self-judgment and sense of self. Building on this, in this section we outline strategies for how designers can use these theoretical concepts to design integration systems (for overview see figure 5). In particular, we focus on methods to elicit a sense of self which is significantly more challenging than altering self-judgments.

4.1 Design Strategies for Eliciting a Sense of Self

Research reveals the sense of self to be constituted by both a **sense of body-ownership** and a **sense of agency** [30, 72]. We can observe the difference between these two senses when one's body is pushed involuntarily by someone else. For instance, when I am being pushed, someone else initiates my movement, resulting in the feeling that my body moves without my intent. Consequently, I maintain a sense of body-ownership while losing a sense of agency. Contrarily, if I move someone else around, I might feel that I am initiating their movements but not that their body is mine, and thus a sense of agency is maintained but not a sense of body-ownership. Being able to design integration systems that elicit both these senses will lead to the fundamental feeling that the integration is a part of the user - even when the user is not reflectively aware of the integration.

4.2 Eliciting a Sense of Body-ownership

The Sense of Body-ownership is the pre-reflective awareness of myself as the subject moving or having a certain sensation (e.g. a kinaesthetic experience of movement or tactile sensation of touch) [83]. For prosthetic users, the sense of body-ownership often equates to sensations being felt on the prosthesis. For instance, prosthetic users often speak of being able to "feel my [prosthetic] heel land", feel "the [prosthetic] foot move forward", or feel the "things that come into contact with it [the prosthesis]" but that these feelings are minimal and that the users do not pay much attention to them when using the prosthetic as it has become pre-reflective [63]. Given the pre-reflective nature of the sense of body-ownership, eliciting a sense of body-ownership requires a multifaceted effort — summarized by two key factors including multisensory correlation and body-model compatibility.

Multi-sensory Correlation. From a neurocognitive standpoint, a sense of body-ownership is generated from and sustained by bottom-up sensory information such as tactile and visual feedback [83]. For instance, in order to induce a sense of body-ownership, objects are usually integrated via multi-sensory correlations, such as synchronous visuo-tactile stimulation on the object and a real body-part (as seen in the Rubber Hand Illusion) [83]. To elicit a sense of body-ownership, researchers should therefore consider ways in which their integration can provide the users with sensory information, for instance by stimulating a real body part of the user at the same time as the integration.

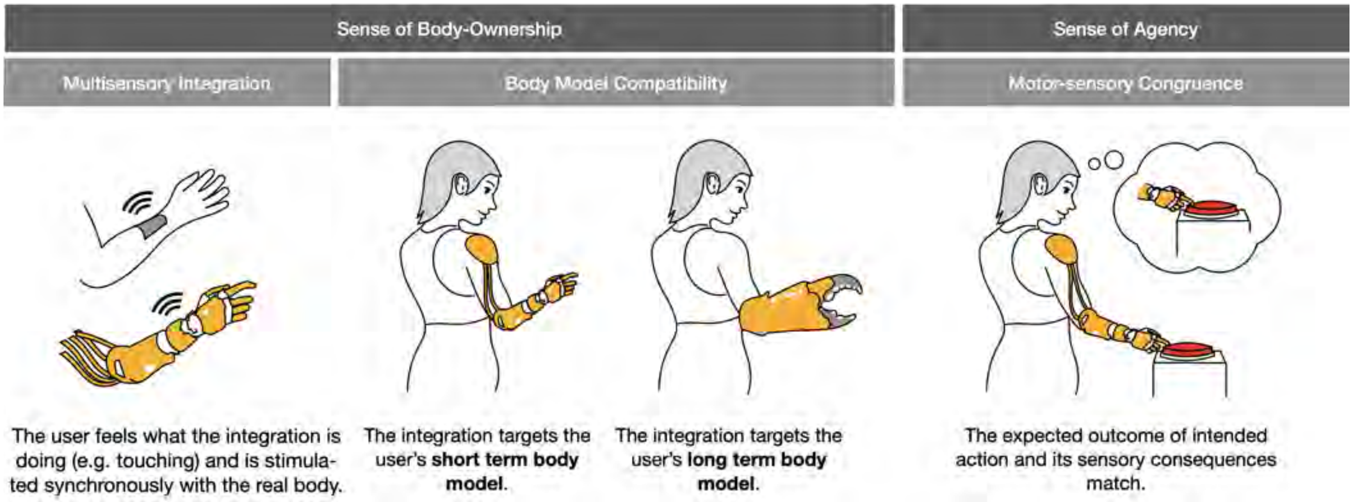

Figure 5: Strategies that designers should consider to elicit a pre-reflective sense of self.

Body-model compatibility: Short-term integration with strong body-similarity. From a more cognitive-neuroscience perspective, according to Tsakiris et al., a sense of body-ownership seems to also require the form of the device to fit closely within a general pre-existing cognitive model (non-conscious) of one's body, and not to be "a neutral object that has no functional connection with the body" [83]. This means that the device should be in an anatomically plausible posture and position while being somewhat close to the shape of the user's body [83]. However, as we will argue in the following subsection there might be some exceptions that allow for non-anthropologically similar integrations but require more time to elicit a sense of body-ownership.

Limitations vs opportunities in body-model compatibility. The notion of body-model compatibility presents a critical question to what we as HCI researchers aspire to achieve: is it possible to be in and feel a sense of self in novel bodies? From extra fingers [44], extra arms [74], to robotic tails [78], it is unclear to what extent integrations can be compatible with our body and to what extent they cannot. Studies in cognitive science attempt at informing us of such limits; two recent studies have shown it possible to simultaneously feel a sense of body-ownership towards a third (rubber) hand [19, 64] and have "ownership responses" over certain non-anthropomorphically shaped artifacts (such as flinching behavior when it was threatened) [77], despite other researchers having shown that we cannot feel a sense of body-ownership over objects with dissimilar morphology [59] such as sticks [83]. The reason for these seemingly contradictory results, is suggested to be caused by two different body model constraints in regards to eliciting a sense of body-ownership: a long-term-body-model (LTBM) and a short-term-body-model (STBM) [16]. The Short-Term-Body-Model allows for small modest bodily changes while still maintaining a sense of body-ownership. This means that anything which closely enough resembles our real body (like a rubber hand) can be easily felt with a sense of body-ownership after just a few minutes of multi-sensory stimulation. The Long-Term-Body-Model, on the other hand, is a less elastic body-representation that includes what "should be located in the phenomenal field in a specific way" such as two hands and not 12 lobster claws [16]. Altering the long-term-body-model, has not been empirically validated yet but is expected to take longer than just a few minutes [83]. To elicit a sense of body-ownership over integration systems, researchers should consider the similarity between their integration and the users body model depending on whether their form-factor requires for a short-term or long-term integration. If the integration is in a non-anthropomorphic form-factor, we encourage researchers to evaluate if there is a change in sense of body-ownership over months and share their results.

4.3 Eliciting a Sense of Agency

The sense of agency is the pre-reflective awareness or sense that I am the one causing the action of an object [83]. The sense of agency is perhaps the most common pre-reflective experience that we have of objects: when skillfully eating with a fork, driving a car or using a tool, we do not need to think about how we are using them - they just do what we intend them to. Similarly, in the literature, we find that a sense of agency correlates with feeling that intended actions are done "intuitively", without the continuous reflective monitoring and "awareness of [the integration]"[63]. As one prosthetic wearer says: "[when using my prosthetic] it's pretty much a matter of well I want to go from here to there. I just walk."[63]. Additionally, losing a sense of agency has also been shown to diminish senses of body-ownership. Research on the rubber hand illusion shows that after a sense of body-ownership is elicited, moving the rubber hand involuntarily (while the participant's real hand does not move) disrupts sense of agency and leads to a diffused or weak sense of body-ownership over the rubber hand[16, 47, 83]. Thus, for designers to effectively elicit a sense of self in their designs, it is essential to consider both a sense of body-ownership and a sense of agency.

Congruence of Intended and Real Sensory Consequences of Actions. For designers to effectively elicit a sense of agency in their designs, research shows that congruences between intended sensory outcomes and real sensory outcomes are essential[83]. For instance, I expect that moving an integration in a specific way will lead to a certain proprioceptive, tactile, or visual sensation (e.g. seeing that the integration has moved from A to B), and not having these sensory outcomes removes my sense of agency. We all know this from when our devices or even our body breaks down and we feel that we can no longer control them as skillfully as we expect. Further, not only must the outcome (e.g. movement) closely match the intention, but the match should also not happen after around 200ms of initiation[37]. If the match between intention and sensory consequence is less than 200ms it is often perceived as an involuntary action[60]. In this way, researchers should consider ways in which their designs allow users to effectively and pre-reflectively realize their intentions without too much friction and time delay.

5 EVALUATING A SENSE OF SELF

So far, we have discussed the theoretical and practical ways in which researchers and designers might elicit a pre-reflective sense of self over their technology. But how can we be sure that a technology actually elicits a sense of self? As guidelines, these conditions will be imperative in designing and experimenting with technologies that experientially integrate with users' self-experience; however, we also need to validate whether such experiences are effectively elicited (or diminished).

5.1 Current Evaluation Methods for Sense of Self

Physiological Measures. Popular methods to evaluate the presence of a pre-reflective sense of self include various physiological and behavioral measures with the 2 most prominent being: (1) increased skin conductance when an integration is threatened [31, 39, 77], and (2) task performance [4, 41, 77, 88]. Skin conductance is the phenomenon that the skin momentarily becomes a better conductor of electricity when stimuli occur that are physiologically arousing. Performance measures can be the time is takes to complete a task, the extent to which the user is successful, or their final score.

While such physiological measures are thought to correlate with an induced sense of self (although questioning by some researchers [54]), they are in themselves not sufficient to make precise claims about self-experience. For instance, increases in users' skin-conductance are often caused by other factors than threat such as attention, habituation, arousal, and cognitive effort [22, 54]. Similarly, increased task performance can occur without integrations being felt with a sense of self. Many prosthetic users are very skilled but do not necessarily feel a sense of self over their prosthetic limb [63].

Since self-judgments and sense of self are self-*experiences* and since their *physiological* correlates are not yet well understood, investigating them requires both physiological and qualitative methods. In particular, qualitative methods that can systematically identify their presence in experience.

Qualitative Measures: Questionnaires. A popular method for measuring sense of body-ownership and sense of agency is through questionnaires [4, 15, 31, 35, 37, 40–42, 74, 77, 85, 88]. While questionnaires are easy to use and quantify, they rely on the user's reflective judgment and are thus influenced by the user's beliefs, which hinder an unbiased assessment of the pre-reflective aspects of experience and make it hard to tell if the results are about self-judgments or sense of self [50]. For example, if a questionnaire asks participants to rate the sense of body-ownership over an artificial hand, the subject would then reflect on and judge it — e.g. "do I perceive this to be my own hand?". In such a judgment, the subject might think to themselves that the integration looks very much like their hand, and thus that it must be theirs regardless of whether they pre-reflectively feel it or not [27, 50]. Consequently, questionnaires that investigate 'body-ownership' and 'agency' may thus fail to distinguish between participant reports of pre-reflective senses and reflective judgments [16].

Qualitative Measures: Idiosyncratic Interviews. It has been suggested [62] that instead of using questionnaires, HCI researchers should focus on other qualitative measures, such as either the "Explicitation Interview" technique [57] or variants like "Micro-phenomenology" (M-P) [73]. Unlike questionnaires, these techniques focus on "unfolding tacit embodied dimensions of experiential content" beyond one's reflective understanding [73].

While these techniques enable a greater understanding of implicit aspects of experience, they primarily focus on idiosyncratic experience, that is population- or individual-specific knowledge [73]. Because of this focus, such techniques only let us understand the experience of one particular individual rather than invariant structures across individuals. Evaluating whether an experiential structure such as sense of self is present or diminished requires us to approach experience much more like a science, where we can isolate invariant phenomena and make generalizations. Therefore, the validation of these parameters requires a methodology that is more capable of scientific observation devoid of idiosyncrasies [27].

5.2 Evaluating Experiential Integration Systems with Phenomenological Interviews

We argue that in order to systematically evaluate experiential aspects of being integrated with a device, phenomenological interviews might be useful [33]. In a phenomenological interview, which is an extension of the explicitation interview, the interviewer engages collaboratively with the interviewee to generate knowledge together about the interviewee's lived experience. This is done by actively questioning the experience with open "how questions" to reveal the pre-reflective aspects of the experience in as precise detail as possible. Being a relatively new method, the phenomenological interview has so far been used in literature to investigate pre-reflective structures of experience such as sense of agency in cerebral palsy and musical absorption [1, 32, 55]. Using the phenomenological interview, for instance, Høffding et al. [32] have been able with members of a quartet to generate long and precise descriptions of pre-reflective experience when performing which pointed to a change in the sense of agency during an experience of deep musical absorption. In another study, the phenomenological interview was used to develop a person-centered intervention to address the experiences of bodily uncertainty in individuals with cerebral palsy[1, 55]. For the latter, the phenomenological interview was used to first assess the experiential distortions of body-experience when living with cerebral palsy (e.g. a reduced sense of agency on some body-parts in particular situations), and then to evaluate the implications of a therapeutic intervention on these distortions (e.g. an increased sense of agency on some body-parts in particular situations) [1]. Using phenomenological interviews in these cases enabled the researchers to go beyond merely understanding the experience of musical absorption or bodily uncertainty for single individuals, which is the focus of idiosyncratic methods, and instead say something general about musical absorption and bodily uncertainty as a whole.

We propose that the Phenomenological Interview is particularly useful as compared to currently used methods for evaluating experiential aspects of selfhood as (1) it aims to arrive at subject-invariant detailed descriptions of particular (pre-reflective) structures of experiences, rather than idiosyncratic descriptions, (2) the interviewer is well-informed of relevant phenomenological concepts such as sense of body-ownership and agency which guides what to focus on with the open questioning, (3) the collected descriptions are after the interview subjected to phenomenological analysis in which descriptions are aligned with phenomenological and scientific concepts in order to say something general about the experiential structures under investigation[33, 93]. As stated by Høffding et al.:

> "the focus of the phenomenological interview is not *only* to understand the experience of the interviewee, but more importantly to understand the invariant phenomenological structures of this experience. [. . .] In this respect, and as phenomenologists, our questions have a different orientation from those of qualitative researchers, anthropologists, ethnographers, sociologists and psychologists" [33].

Further, phenomenological interviews, we believe, can help understand, identify and avoid potential elicitation of experiential disruptions such as a self-alienation or depersonalization in designs. By continuously asking questions, researchers will be able to dig deeper into the experience reported by users. For instance, if a user reports that a device is experienced like "an extension of themselves", asking further questions could reveal whether that experience is a conceptual, emotional, or perceptual self-judgment (e.g. "it is attached to me, so it must be me", or "my doctor told me it is me") or if it is a pre-reflective sense of self (e.g. "I feel my heel land", "It just happens intuitively without much thought").

Conducting a phenomenological interview.

Step 1: Generating Detailed Descriptions of Experiential Structures. As a first step, to generate detailed descriptions, Høffding et al. [33] suggest using the Explicitation Interview [57] which the phenomenological interview is an extension of [33]. This is done through a semi-structured interview with each user in which the interviewer tries to motivate them towards giving detailed and concrete descriptions of particular lived experiences in certain situations. For example, if the interviewer open up with a general questions, such as "Can you describe how you experience the robotic arm?", and the participant answer with scientific or mechanical explanations ("A motor in the arm initiates..."), the interviewer will then persist with further probing fine-grained open 'how' questions, until the participants offer very detailed descriptions of their bodily experience in specific situations (e.g. when pressing a button, lifting something, having a conversation etc.) [33, 93]. Asking open "how questions" is particularly useful as they are not concerned with the idiosyncratic or reflective content of experience per se. Instead, open "'content empty' questions help the subject to become aware of the different structural—diachronic and synchronic—dimensions of his experience, to reveal pre-reflective experience, and to give a verbal description of them"[33]. By using continuous probing and open "how"-questions, we can go beyond users' reflective judgments and make explicit the underlying pre-reflective structures of a particular experience[33]. Since this method is very new, it has not yet been used within HCI but to get an understanding of how it could be used within an HCI context, take this report made by Kevin Warwick after being implanted with an RFID chip allowing for the transponder to emit signals that operate doors, lights, heaters and other computers in his laboratory automatically [87]. He describes his experience with the implant in the following way:

> "[. . .] Every day in the building where I work, things switched on or opened up for me - it felt as though the computer and I were working in harmony. As a scientist, I observed that the feelings I had were neither expected nor completely explainable - and certainly not quantifiable. It was a bit like being half of a pair of Siamese twins. The computer and I were not one, but neither were we separate." [87]

In this statement there are some hints with regards to device feeling somewhat as part of Warwick's self-experience but it remains vague in which specific way this is the case (self-judgment, sense of self, or none). Using the phenomenological interview we could potentially explore these experiences in more detail by asking questions such as "How/when were you and the computer working in harmony?", "In what way were you and the integration not one?", "How were you not separate?". By getting answers to these questions and probing until we get very precise descriptions of the experience, we might be able to get a better understanding of what it means to be integrated with an RFID chip implant, and what impact it had on Kevin's self-experience. For instance, by Warwick's report of the chip being "not separate" did he mean their were not separate based on literal sense as he knew the chip was physically inside him (self-judgment), or based on a feeling that they were not separate (sense of self)? This difference could be more clearly revealed by asking "How were you not separate"?

Step 2: Phenomenological Analysis. To perform a phenomenologically informed analysis of the generated descriptions from step 1, the phenomenological interview relies on the analytical work of phenomenology (such as work on pre-reflective awareness, reflective awareness, sense of body-ownership, and sense of agency). In the phenomenological analysis step, descriptions from the first step is grouped into experiential themes or specific phenomenological concepts, such as sense of body-ownership and sense of agency[33]. For instance, asking questions about Kevin Warwick statement in the previous paragraph of "working in harmony" might reveal feelings of "I did that" in situations where the outcome of the chip matched his expectations, or feelings of "the technology did that for me" in situations where they did not match. Taken together, these descriptions could help us define whether and in which situations the RFID chip was felt with a complete, or perhaps just weak sense of agency. Similarly, asking questions about how he was "not being one" with the integration could reveal if the implant caused a diminished sense of body-ownership or not.

5.3 Phenomenological Mixed Methods: Combining physiological data and phenomenological interviews

Finally, to arrive at the most comprehensive analysis of changes in self-experience from an integration, researchers argue in favor of a mixed-methods approach that seeks to combine physiological and qualitative data. In a *phenomenological mixed method* study, the aim is to "correlate the data and analysis from the [...]phenomenological interview with the data and analysis generated from quantitative methods" [56]. This can be done by either first (1) conducting an exploratory phenomenological interview to identify experiential structures associated with sense of self, or if those structures are already known, (2) use them to inform interviews and collection of quantitative data in another experiment. As an example, the first approach has been used to identify specific categories of disturbances of self-experience in patients with schizophrenia spectrum disorder and develop a quantitative measure for diagnosis [71]. As an example of the second approach, researchers have investigated bodily uncertainty in patients with cerebral palsy by first collecting eye-tracking and body-movement data in a collaboration task and then conducted phenomenological interviews to get descriptions of participant experience. Combining the quantitative and qualitative data, the researchers found a direct relation between the functional and experiential dimensions in joint actions [56]. Similarly, using phenomenological mixed methods for evaluating self-experience (self-judgments or sense of self) can help us reveal certain experiential structures of the experience and correlate them with physiological data to get a broader and more precise perspective on an integrations impact on self-experience.

6 DISCUSSION

In this paper, we have presented theoretical concepts, practical design and evaluation methods from research in phenomenology, cognitive science and neuroscience that we consider essential in eliciting a sense of self and advancing experiential aspects of integrations in HCI. We believe this advancement to be necessary for future integration systems as well as to enable novel opportunities and applications for future design and research. However, we might not always need to feel a sense of self over an integration - having pre-reflective feelings such as a sense of agency without sense of body-ownership, can also have many benefits to design for. Lastly, the amount of time in which someone uses an integration also seems to play an important role in generating pre-reflective feelings and eliciting a sense of self.

6.1 One might not always want to feel that an integration is part of them

We might not always want to feel a sense of self over certain systems. When leaving a car it should not feel like leaving a part of your body behind, when leaving a fork on your dinner table it should not feel like you are leaving your hand behind, or when leaving your notebook on your desk should not feel like your memories are left behind. Moreover, there seems to be something positive about experiencing some things as "other" rather than "part of us". For instance, having some devices be felt as 'other' might allow someone to more quickly transition between newer devices. Further, someone could be able to care less about the damage inflicted on the integration - which could be beneficial if the integration was to be used in hazardous environments where it is likely to get damaged. Lastly, diminished sense of self over someone's own body could also allow them to more easily let go of it up to an amputation [61].

6.2 Feeling a sense of self might take a long time

Being able to pre-reflectively experience something seems to take time. In the rubber hand illusion, researchers copy the body and thus leverage the experiences that users already have built up over their own body to quickly elicit a sense of self. Similarly, EMS systems actuate the user's own body that is already felt with a sense of body-ownership, and thus only need to be concerned with eliciting a sense of agency to sustain a sense of self. However, making novel integrations pre-reflectively felt with a sense of self might require long-term use of the integration [16]. Over time, we can observe how using, for instance, a computer mouse, at first might require reflective awareness of which hand movements make the mouse go in which direction, while over time with training the mouse become somewhat pre-reflectively felt. Similarly, studies on prosthetic users have, for instance, shown that while some prosthetics are initially reflectively experienced, over time and with training, the experience of them tend to become pre-reflective and the user satisfaction increases[63]. This was also found in another study, where a belt signaling to the users where the north was after being worn for a month was no longer "[reflectively] perceived" but rather became "a direct feeling of knowledge"[38].

We therefore note that one benefit of formalizing the concept of sense of self and methodologies for evaluation in HCI is its potential in understanding the implication of applied, long-term integration of novel technology on self-experience. Most previous work in cognitive science is limited to short-term intervention, where most applied studies remain in prosthesis or rehabilitation studies. Thus, there is a gap in our understanding that, with regards to emerging intervention methods such as supernumerary limbs or novel VR avatars, that are primarily investigated within HCI or HCI-related fields, could be further explored. Conversely, grounding these HCI works within established concepts and methodologies from phenomenology and cognitive science could help filling the gap in our understanding and insight gained from using these concepts could vice versa inform phenomenology and cognitive science research — especially on whether it is possible to alter the Long-term Body Model.

A notable example where time and the long-term body model could be an interesting factor to explore, is an experiment by VR pioneer Jaron Lanier, who discusses embodying as a "lobster" avatar in a virtual space[89]. Won et al[89] argues based on their VR experiment, in which subjects have three arms or alternative configurations, that radical "avatar alterations" may be possible. And while neuroplasticity might support that altered body configurations can cause changes to the somatosensory cortices of the brain[36], it is unclear whether these changes are caused by feeling a sense of self over the configurations, or whether the user is just learning to use the configurations skillfully without a sense of self. As has been indicated in research on prosthetic users, for instance, it is entirely possible to be a successful user without necessarily feeling that the integration is part of you[63]. Unfortunately, the experiment by Won et al[88] primarily focuses on the sense of agency that is only one sub-component of a sense of self. Thus, having a common understanding of the two notions of self-experience; self-judgments and sense of self, we expect to see deeper investigations of such radical possibilities with the exploration of novel systems in HCI, such as previous works [45, 67, 68, 74, 90, 91], through the methods and focus on experiential aspects of integrations presented in this paper.

6.3 Limitations

This work is only a "starting point", rather than a complete articulation of how to design experiential integration. Future work can build on this by designing novel integration systems and using phenomenological interviews to investigate experiential structures and their elicitation (or lack thereof), and how they are influenced across time, form factor, sensory modalities and so on. Given the various opportunities and articulation of how we might design technology that becomes a part of our self-experience as introduced in this paper, we hope research in HCI and other related fields will be able to make informed design and evaluation decisions in terms of promoting methods that elicit a sense of self. However, as research within this field is still experimental and developing, the paradigms and knowledge will continuously evolve, with many unknowns ahead. We therefore hope that our outline will not just benefit designers — but also the phenomenological and cognitive science research to which these results might be of use. We intend this research as groundwork for future updated frameworks –as we obtain a deeper understanding of human cognition and study diverse prototypes that may showcase new research problems. The paper aims at suggesting different notions of self-experience and showing the limitations of using reflective methods (that relate to self-judgments) when trying to evaluate a pre-reflective sense of self. The paper thus suggests a shift of focus from merely physical and functional integration, and reflective experiences such as self-judgments, towards a pre-reflective experiences such as sense of self, which we see as a shift most critical for systems deployed in the wild. As a result, a design guided by our framework may face unexpected results, as our bodily experience may be, and would be, influenced by a larger set of parameters not possibly covered in this paper. This is the main reason why both the design and evaluation phases of self-experience design are critical, in which investigation of pre-reflective aspects of a system could help identify human factors that were not considered in the design phase.

7 FUTURE WORK

In this paper, we expand the conversation on Human-Computer Integration (HInt), which focuses on physical and functional integrations of technology and the human body to include experiential aspects of integration. In particular, we explore the current research on how to elicit an experience of being part of a technology. As research has shown that not thinking about such experience, the technology can create unpleasant, disembodied, or dissociative self-experiences, despite being able to increase functionality and performance. Our framework would strengthen the sense of self in a system that can augment human capabilities such as electrical muscle stimulation (EMS) to make the users feel that they are the one doing it, rather than the machine, or making prosthesis feel more natural and seamless, and avoiding dissociation. Our framework could also reduce the experience of self in some technology that need dissociation from the body and creating resilience against technological overreliance. We believe that our work would open new possibilities, and enable a new design paradigm for researchers and practitioners in the field.

These issues will increasingly become critical, as we see more research towards said "invasive" technologies. For such systems to be engineered for experience, a formalized evaluation metric both in terms of its performance and experience should be adopted, and further discussion on how these factors are considered in the process of designing such systems are necessary. In addition to avoiding negative psychological effects such as dissociation, feeling that a technology is part of a user could also lead to an increased ability for them to protect their integration, and use it more naturally as the integration is expected to always be available.

We argue that designers are well advised to consider both self-judgments and sense of self when thinking about human-computer integration technology and self-experience. Making this distinction enables more precise research, novel opportunities, and, as we will argue, increases the likelihood for success. We hope an increased focus on experiential integration with regards to self-experience will motivate future work and support researchers within Human-Computer Integration to consistently and systematically investigate the self-experiences of users, while taking the first-person perspective of human-computer integration systems seriously.

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