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Taking inspiration from becoming "one with a bike" to design human-computer integration

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1. Introduction

Within HCI, there appears to be an interest in the human-computer integration paradigm (Farooq & Grudin, 2016; Grudin et al., 2018; Mueller et al., 2020), wherein computer and user form a close partnership to jointly interact with the world around them, contrasting a traditional "command-response" interaction. Integrations can occur on a bodily level (Mueller et al., 2021), resulting in computational system and human body "fusion" (Mueller et al., 2020) where the machine "extends the experienced human body or [. . .] the human body extends [the machine]" (Mueller et al., 2020). Integration systems do not require explicit input from the user, but simply act as an extension of the user's body (Mueller et al., 2020). However, not all cases where technology and the human body physically connect are integration systems. Mueller et al. provide as a counter-example a pacemaker as it acts below the perceptual threshold, has neither an interface nor provide the user with any agency (Mueller et al., 2020).

We describe the resulting integration experience as becoming "one" with the system. This integration trend has been fueled by increased interaction design interest in paying attention to the human body (e.g. (Dourish, 2001; Höök, 2018; Mueller et al., 2016)), along with technological advancements such as sensor miniaturization, actuator capabilities, data processing speed, and battery performance. The results are often captivating integration experiences, including: an electrical muscle stimulation system for handwriting manipulation (Lopes et al., 2016); bodily extensions in the form of additional arms (Sasaki et al., 2017); and robotic human tails (Svanaes & Solheim, 2016).

However, amid these advancements, prior research lamented that it is not yet completely understood how to design systems that make full use of the opportunity to integrate human bodies with computational machines (Mueller et al., 2016). To address this, it was suggested to dive deeper into understanding the human body in order to design better systems (Marshall et al., 2016; Mueller et al., 2016). Building on this, we are proposing to more explicitly consider the fact that a user is able to engage their body both consciously and subconsciously, significantly influencing the extent to which integration can occur.

The human-computer interaction field will be unnecessarily constrained if we continue to adopt a limited view of how the human body engages with integration systems, and users will be unable to profit from the experiences afforded by integration (Farooq & Grudin, 2016; Mueller et al., 2020). To help interaction designers go beyond this limited perspective, we take inspiration from the integration that riders can experience with their bikes, becoming "one with the bike." As such, HCI can take inspiration from bikes, including push-bikes, motor-bikes, and eBikes (the world's fastest growing bike category (Intelligence, 2019)). While bikes have many environmental (Johansson et al., 2017), mobility (Pucher et al., 2010), and health

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(Oja et al., 2011) benefits, we focus here on the potential for riders to become "one with the bike" (Spiegel, 2019): to experience a tight integration with the bike, where the idea of the bike as a system dissolves into the user's own body while riding; to experience a feeling of having somehow absorbed the bike, as if it has become a part of the rider, or conversely, as if the rider has become part of the bike. Spiegel (2019) argues that such integrations produce a new unit with new system characteristics, greater than the sum of its parts. The result could not only be safer (Spiegel, 2019), but also more enjoyable and engaging integration experiences in which the user becomes more aware of who they are and who they want to become, including how to get there (in our case, from realizing the benefits of riding a bike, such as when ordered by a doctor, to "becoming a rider") (Mueller & Pell, 2016; Mueller & Young, 2018). Furthermore, we also note that unlike prior work on integration, which noticed that associated investigations "often only affect a sub-part of the user, such as a limb or a sense" (Mueller et al., 2020), we focus on bike riding and hence the whole body of the user.

An awareness of prior work on rider and bike integration can be useful for interaction designers. Bikes are used by millions of people worldwide, across cultures, so many interaction designers might be able to relate to this integration through first-hand experience via a "bodily way of knowing" (Höök, 2010). Also, bikes offer an affordable entry point into integration (unlike complex robotics infrastructure (Nabeshima et al., 2019; Sasaki et al., 2017)) that can be readily introduced to, for example, studio design practice and design student teaching.

We extend existing knowledge on human-computer integration by introducing prior (non-HCI) work on bike riding. In particular, we articulate how an integration experience can benefit from design that engages both the conscious and subconscious self and their transitions. Unlike prior work that mostly focused on integrating specific device characteristics (e.g. (Farooq & Grudin, 2016; Grudin et al., 2018; Mueller et al., 2020)), we discuss how successful integration benefits from not only a well-designed computational machine, but also from support for the user. We argue that the rider uses their conscious and subconscious self for successful integration and, in combination with our experiences of having designed four research-through-design bike systems, we articulate five themes for the design of future human-computer integration systems, referencing specifically: an interactive biosensing helmet; a leaning-sensitive eBike; an eBike that helps crossing lights at green; and an EEG-connected eBike. We use our craft knowledge and insights from associated studies to suggest ways that designers can use interactive technology to implement the five themes (conceptual aid, sensorimotor coupling, uncontrolled flow, evidential experience, agency) when aiming to engage the conscious and subconscious self in future human-computer integrations.

In summary, this article aims to aid practitioners interested in designing integration systems, and to support researchers seeking a structured understanding to better understand and evaluate integration experiences. We contribute to knowledge on how to design the integration between humans and computational machines in order to create engaging user experiences. As such, our work begins to address the gap in knowledge about how to design integration systems. We do so by providing knowledge around the design for the conscious and subconscious self during integration experiences. With this, we hope to allow more people to profit from the benefits of the associated experiences.

2. Related work

We are guided by prior work on the coming together of the computational machine and the human body. In particular, we draw from previous investigations that promote an increased attention to the human body in HCI, including sports-HCI, and the coming together of HCI and bikes.

2.1. *The coming together of the human body and computational machine*

The idea of integration goes back to at least 1843, when Edgar Allen Poe described a man with extensive prosthesis as a "man-machine mixture." Since then, the idea has been discussed in related and overlapping areas, including cybernetics (Ashby, 1961), intelligent augmentation (Engelbart, 1962; Mann, 2001), cyborgs (Clark, 2001; Haraway, 2006), and wearables (Starner, 2001; Steimle, 2016). Decades ago, Wiener (1948), then Licklider (1960), proposed that designers could look at other domains (animals, trees) to learn how to create an integration between human body and machine, which inspired us to look into the integration between rider and bike. Later on, Haraway argued against a rigid boundary separating human and machine (Haraway, 2006), inspiring our proposition that both the machine and the human can be "designed for" when it comes to integration. Clark proposed that integration is already present with eyeglasses, etc (Clark, 2001). We agree and extend this (analog) work by presenting the first insights on how to draw from bike riding and (digital) bike development to advance human-computer integration. More recently, Höök drew lessons from horseback riding (Höök, 2010), pointing out that the rider initially just sits on the horse, like a piece of cargo, but over time, can become "one" with the horse, resulting in a half-man and half-horse experience, almost like a centaur. We argue that a bike rider can undergo a similar transformation. Similarly, Goodrich and Schultz were equally inspired by horse riding; they suggested to draw from it for the design of human-robot interactions (Goodrich & Schultz, 2008). Norman studied riders and horses (Norman, 2009) and proposed the terms "reflective" and "visceral" to describe the different levels with which the two interact. This framing aligns with our focus on the conscious and subconscious self and we extend this prior work by articulating what this means in the context of integration with non-living systems.

We note that if we talk about integration, we refer to integration specific to interactive, digital technologies. For this, we build on prior HCI work that highlighted the value of drawing on extended cognition theory for the design of bodily systems (Bødker, 2015), realizing that interaction design is also moving outside the workplace (Harrison et al., 2007), which speaks nicely to our bike systems that were all studied outdoors. However, we find that most prior work on extended cognition outside the workplace did not consider much how users experience an integration with an interactive system nor how to design for this integration to occur, hence we decided to write this article. Moreover, we note that prior work on extended cognition has already argued that human cognitive states and processes can spill outside people's heads and into objects, in particular, second-wave arguments have emphasized the ways in which human bodies can integrate with our environment (Sprevak, 2019). This prior work argued that our brains, bodies and the environment can be "so tightly intertwined that [...] they count as a single system" (Sprevak, 2019). This intertwinedness speaks nicely to our notion of integration (Mehta et al., 2018; Nylander et al., 2014; Pijnappel & Mueller, 2014), however, arguments around extended cognition focused on "certain cognitive tasks" and have therefore been criticized for only considering "cognitive, information-processing aspects of mental life" (Sprevak, 2019), hence our work extends this prior work by considering the active human body, here, riding a bike.

2.2. *Increased attention to the human body in HCI*

HCI has also already looked at prior theoretical work in order to understand how to design for the human body (Jensen & Mueller, 2014; Marshall et al., 2016; Mueller et al., 2010; Mueller et al., 2012; Mueller et al., 2014; Nylander et al., 2015). In particular, prior embodied interaction design work looked to Merleau-Ponty (1945) in order to better understand how perception is grounded in action (Svanæs, 2013). Such leaning on prior theory can help understand the bodily experience people can have with interactive systems (Mueller et al., 2020), however, Merleau-Ponty's writing is rather abstract and hence does not often lend itself to concrete design guidance that could help in designers' day-to-day practice (Mueller et al., 2018).

We are also inspired by the TEI community's investigations into how people engage with tools (as a bike starts off as a tool that then becomes part of the rider's body), and how such tool use can change over time. One example discussed repeatedly in HCI is Heidegger's hammer which moves from what he calls present-at-hand to ready-at-hand (Dix, 2010), as the hammer is undergoing, over time of use, a transition from being considered an external object (tool) to an extension of the body. This transition aligns well with our understanding that humans can engage with an integrated system through the conscious (tool) and subconscious self (extension of the body). Nevertheless, we note that knowledge of how to design for these levels of engagement and their transition is still underdeveloped (Antle, 2009).

Klemmer and Hartmann presented a set of themes to aid designers of systems intended to exceed the traditional command-response interaction paradigm (Klemmer & Hartmann, 2006). These themes, highlighting "performance" and "risk," align well with the attention we give to how coaches enhance performance through tighter rider and bike integration while managing risks (Spiegel, 2019).

We are also inspired by prior work on sensory substitution that highlighted that interactive tools that provide new senses can help people experience the world in novel ways, such as expressed in the study around the enactive torch (Froese et al., 2011). Such investigations confirm our belief that people can experience an integration with an interactive system even though not immediately, but after a short time. The same applies to bikes, where integration does not occur immediately, but after learning how to ride it, can be experienced after a short time. The notion of sensory substitution also speaks nicely to prior cycling work that argued that riders experience the road that they are cycling on through the tires of the bike, here, the system does not substitute a sensation but rather transforms it (Ilundáin-Agurruza et al., 2013). However, we believe that how to design for this, especially in a complex outdoor environment where some cycling actions can happen very fast (in contrast to, for example, the slow navigation task with the enactive torch (Froese et al., 2011)) is still underdeveloped.

We are also inspired by work from the augmented human community, such as wearable systems that allow users to see light across different spectra by, either consciously or subconsciously, squinting the eyes (Schmidt, 2017). We investigate what this example of both conscious and subconscious engagement with technology means for an integration experience.

2.3. *The coming together of HCI and bikes*

HCI investigations have also previously already focused on bikes. For example, a study using mobile phones attached to handlebars identified the importance of considering "riding proficiency" (Rowland et al., 2009). This finding aligns well with our proposal that greater proficiency allows the integration experience to move from the conscious to the subconscious self.

Prior work also investigated alternative output modalities besides the traditional screen as they might lend themselves to cycling. For example, Steltenpohl et al. suggested a vibrating belt as a way to help cyclists navigate instead of using a traditional handlebar-mounted display showing map information (Steltenpohl & Bouwer, 2013). Their work confirmed our assumption that designing for bike riding is different from most traditional HCI projects and needs to consider that riders might focus their attention to the environment around them, including traffic, speaking to the requirement to design both for the conscious and subconscious self. However, this prior work has yet to investigate how such alternative output modalities can help integrating with the bike to become "one."

Prior work also used an olfactory display on the handlebar, seemingly similarly responding to the fact that the rider might be occupied with traffic and can therefore not focus on a traditional display (Key & Desjardins, 2019). This work highlighted that owners can experience very intimate relationships with their bikes, speaking to our notion that integration with bikes is a fascinating topic for HCI to learn from.

Pielot et al. used a traditional display to investigate how cyclists could be supported in their quest to explore their environment, rather than finding a specific destination (Pielot et al., 2012). Their research highlighted that designing for bikes poses unique challenges, but also opportunities for interaction designers. In particular, we were inspired by this work's finding that not all interactive systems need to support instrumental aspects (here, getting to a destination in the least amount of time), but can also support experiential aspects (here, the joy of exploration through cycling), which speaks to some of our study results in which participants applauded how our designs made the riding experience more enjoyable (which we discuss later).

Claes et al. used an interactive "voting" experience to engage riders while they are waiting at traffic lights (Claes et al., 2016). While we are inspired by this approach to using interactive technology in the urban environment, instead of making the wait time more engaging, we discuss how traffic lights can become part of the integration experience through our "traffic lights eBike."

We also learned from prior work on three of our eBike case studies that presented that technology can act on the exerting user's body based on sensed information, "granting researchers the potential to develop technology that not only 'presents' but also 'acts' on information throughout an integrated exertion experience" (Andres et al., 2022). As such, the authors focused on the eBike's electric engine as a way to interactively support the rider's exertion. We also find the electric engine in eBikes an interesting opportunity for interaction designers to support novel user experiences. However, in this article, we go beyond the engine and look at theory around bike riding more holistically to understand the design of human-computer integration experiences within an interaction design context more generally.

We also note prior studies that added interactivity to bike helmets, including the ability to warn the wearer of hazards en route (Jones et al., 2007). Our discussion elaborates on an interactive helmet's potential to support rider-bike integration, rather than focusing on its technical implementation for delivering warnings.

3. The conscious and subconscious self in integration experiences

Prior work suggests that bike riders know that to excel, they need to become integrated with their bike, which requires riding with their "mind" as well as their"gut" (Spiegel, 2019). This reference to the "gut" speaks to our notion of the subconscious self as the "gut" can be seen as a colloquial term to refer to the subconscious, contrasting the "mind" that then refers to the conscious self. For example, prior work suggested that riders should use their "mind" when planning an overtaking maneuver, but trust their "gut" quickly negotiating a sharp bend (Spiegel, 2019). Riders (and especially motorbike riders) can reach speeds too fast to be handled by the analytical mind alone (Spiegel, 2019). Furthermore, when learning to ride, a person needs to pay full attention to the steering and staying balanced, however, with practice, these activities become "gut-driven," they become "automatic." We believe that how to design for users "trusting their gut" can be challenging if we stick to traditional HCI approaches only that often focus on rational thought and logical reasoning as steeped in Western rational thought. Hence, we propose to go beyond and suggest to draw from prior bike riding theory two terms that have been used to train people to become better riders by helping them to experience an enhanced sense of feeling being "one" with the bike, building on the everyday expressions of mind and gut as exemplified above. They two terms are German: "Ichperson" and "Tiefenperson" (Spiegel, 2002), in English literally "I-person" and "Depths-person," but translated as "Conscious Self" and "Subconscious Self" (Spiegel, 2019).

The idea of the conscious and subconscious self stems from dual-process theories in psychology that aim to govern human behavior into two categories of thinking, often referring to the automatic and reflective mind (Gawronski & Creighton, 2013), or, as made popular by Daniel Kahneman (2011), system 1 that operates automatically and quickly, with little or no effort and no sense of voluntary control, and system 2 that is rather slow and allocates attention to the effortful mental activities that demand it.

The conscious self is concerned with everything that one is consciously aware of and involves thinking, imagining, and deliberate actions; while the subconscious self describes a deeper aspect of ourselves that is less subject to conscious attention (Spiegel, 2019). The conscious self is very good at planning future actions but can quickly reach its limits and require the help from the subconscious self (Kahneman, 2011). People remain generally unaware of their subconscious activities, or notice them after the fact, when they realize that a spontaneous response must have been triggered from "deep within" (Spiegel, 2019). When somebody learns to ride, they engage the conscious self, paying attention to steering and staying balanced, until, with practice, these activities become managed by the subconscious self, requiring less cognitive resources. Noteworthily, the conscious self can come to the fore again: for example, if we are riding a new bike with a different gear system, we consciously need to pay attention again.

While separating the brain into different regions (conscious and subconscious) has already been utilized in HCI (Komninos, 2020), we note that our understanding of the brain remains incomplete, and that the terms conscious and subconscious self are useful but not precise (Spiegel, 2019). In particular, we learned from prior work that has already aimed to unpack the conscious and subconscious self. For example, Rezaee et al (Rezaee & Farahian, 2015) examined different definitions of the subconscious and concluded that scholarly definitions appear to agree that "subconscious" is considered "below consciousness". The authors highlighted that the subconscious is best seen as "a metaphor for the (without training) uncontrollable functions of the brain, such as heart beat [. . .] it effectively runs the body for you, as well as coordinating learned movements such as riding a bike [. . .], the 'subconscious' mind is thought to be 'based' in the brain-stem" (Birch & Malim, 2017). We like that this prior work mentions "training" and "learned movements" in relation to riding a bike, as it nicely speaks to our belief that interaction design has an opportunity to support such training that leads to learned movements.

On the other hand, we also note that prior work has pointed out that there is considerable debate about whether the conscious-subconscious notion is one-dimensional and if we are not better off understanding these terms as not opposites as this might, for example, explain certain phenomena in sports better (Micklewright et al., 2017). As such, we highlight that the conscious and subconscious are not necessarily causal. Furthermore, we acknowledge that our work is only a small stepping stone in the larger area of investigations around the conscious and subconscious, and we believe that with the advances in our understanding of these psychological concepts, our understanding of how to design interactive technology for them will also improve.

Nevertheless, it is commonly understood that the cerebrum – the most "recently" evolved part of the brain – is responsible for higher-level functions, such as thinking and planned muscle movements, while the "older" cerebellum and brain stem control balance, coordination, and fundamental body functions such as breathing.

Interaction design work has previously already drawn upon such a differentiation between the conscious and subconscious, for example when examining the role of biosensors (Benford et al., 2020). In addition, HCI research has pointed to the fact that people's attention moves between the foreground and background when aiming to make sense of implicit interactions (Ju & Leifer, 2008) or unconscious interactions (Wakkary et al., 2016), speaking to the idea of a conscious and subconscious self. Similarly, prior work has argued that there are not only explicit, but also implicit interactions occurring when engaging with computational machines, this aligns with our notion of the conscious and subconscious self especially as this prior work refers to "unconscious" types of implicit interactions (Serim & Jacucci, 2019).

Interestingly, the conscious and subconscious self are not independent from one another but rather interact with each other (Kahneman, 2011). This has been demonstrated in psychology experiments (Dehaene et al., 2006) and applied to behavior change approaches by introducing subtle changes through the subconscious (Langer, 2000), including via the use of interactive technologies (Adams et al., 2015; Pinder et al., 2018).

Consequently, and consistent with prior work (Mueller et al., 2018), we believe that these perspectives on the human body can be useful for design practice. Furthermore, we believe that they are relatively easy to comprehend as they have analogies in everyday expressions and are –

hopefully – easy to teach to students and integration practitioners. In particular, we argue that to facilitate human body and computational machine integration, we need to design for the conscious and subconscious self, and, critically, for the transitions between them. Consequently, the task of designing an integration experience should not only be concerned with the design of hard- and software, but also with the design "of the user" (for example, through the use of training tools such as conceptual aids, which we discuss later), supporting them in making these critical transitions.

In addition, we were also inspired by prior work that stressed the importance of designing for the "periphery" or "what we are attuned to without attending to explicitly" (Weiser & Brown, 1997), This early work informed later HCI research on the interaction-attention continuum that considers various levels of human attention in interaction design (Bakker & Niemantsverdriet, 2016). This research used case studies to make their argument, similarly, we also used case studies to argue our point.

Furthermore, we were also inspired by prior work where some of the authors analyzed three of our four bike systems from an "exertion" (Mueller et al., 2003) perspective (Andres et al., 2022). This suggested that "agency" is important (which we delve deeper into by discussing the management of human and machine agency shifts to engage with the subconscious self). Here, we build on this and present an investigation of four bike systems in relation to the conscious and subconscious self (which the prior work did not discuss) when aiming to facilitate integration experiences.

In summary, although prior work has envisioned human-computer integration, researchers still consider our design knowledge around how to go about designing for it as being limited (Marshall & Linehan, 2017; Purpura et al., 2011). In particular, while research points out that integration could benefit from the understanding that users are not always engaging only in conscious thought, but are sometimes also engaging the subconscious (Mueller et al., 2020, 2021), the knowledge of how to design for this remains scarce. We respond to this with our work by discussing the complexity of bike riding and in particular what role design could play in designing for the conscious and subconscious when riding in order to facilitate an integration experience. Building on this, we propose how rider and bike integration could be generalized across an entire class of integration experiences.

In the sections that follow, we discuss four of our works around bikes and draw upon prior (non-HCI) work on bike riding to present a set of integration experience design themes. We depict how the themes could help integration designers to consider the conscious and subconscious self when aiming to facilitate integration experiences.

4. Bike systems

In recent years, we have developed four bike systems using a research-through-design approach (Gaver, 2012; Gaver & Bowers, 2012; Zimmerman et al., 2007). Each system uses different technologies and had different objectives. Based on our experiences of designing, riding, exhibiting, and reflecting on the design process and associated studies, we have gained intimate knowledge of these bike systems and associated user experiences. This design work informed theoretical thinking around human-machine integration and vice versa, as we realized the overlap between integration's theoretical discourse and our bike designs and rider reports. Throughout this design journey that spans over 7 years, we realized that we lacked a vocabulary for the processes that touch upon the conscious and subconscious and those tricks bike designers, riders and coaches utilize to fuel becoming "one" with the bike. We came across Europe's biggest selling book on motorbikes (Spiegel, 2002): the author, a behavioral psychologist, introduced us to (purely analog) concepts used to train bike riders. We realized that we unknowingly engaged with some of these concepts in our design practice and consequently the book helped us to articulate our tacit (digital) bike design knowledge and translate it, for the first time, to the HCI community by applying it to the human-computer integration agenda.

We have also been involved in the development of the human-computer integration paradigm (Grudin et al., 2018; Mueller et al., 2020) as well as in the discussions around the reporting of design research learnings (Mueller et al., 2022) more broadly (such as advocated by Howell et al. (2021)), which we believe helped our design work: We find that the associated processes enabled us to articulate a set of design themes that others might find beneficial for future integration work. However, we acknowledge that our work evolved organically and does not yet comprise of a complete understanding of how to design human-computer integration, therefore our insights are to be understood as springboard for future investigations that others can build upon.

Lastly, we have also been inspired by the emergence of other related personal mobility devices such as Segways, skateboards, hoverboards, monowheels and eScooters that have gained popularity in many cities worldwide. We believe they hold similar potential like bikes for human-computer integration in an easily approachable hardware platform. However, we leave such explorations to other designers for future work.

We now present our four bike systems.

4.1. *Lumahelm*

Our bike investigations began with the opportunities that helmet augmentation might provide. The resulting “Lumahelm” (Walmink et al., 2013) is an interactive helmet, covered with 104 individually addressable LEDs (Figure 1). We placed an accelerometer inside the helmet that allows the LEDs to light up red to warn people of a braking maneuver. The rider can also tilt their head to make the LED lights blink yellow, indicating upcoming direction changes. The helmet can also display the rider’s heart rate, with the intention of raising other road users’ awareness of a rider’s physiological state (Walmink et al., 2013), offering a previously identified opportunity to improve understanding (and appreciation) between road users (Ducao).

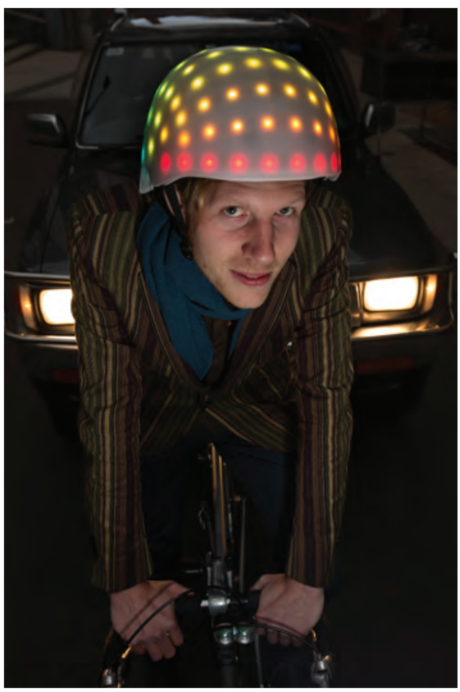

Figure 1. Lumahelm: an interactive helmet.

An in-the-wild study (Rogers, 2011), with 12 cyclists (7 females, 5 males, between 25 and 65 years, average age 47 years) (Walmink et al., 2013), suggested that Lumahelm was appreciated by riders as it appeared to "extend the [subconscious] experienced human body" (Mueller et al., 2020) as part of the rider's (protective) clothing. This work on Lumahelm ultimately led to the EEG eBike that also used headgear, described further below.

Similar projects have emerged since we worked on Lumahelm, suggesting that there is interest in bike design explorations, such as backpacks with embedded displays providing information for people behind the rider ("Pix Backpack," Backpack, 2020), grassroot initiatives to promote equipping helmets with LEDs (Stern, 2013), and a business offering LED-equipped helmets that indicate direction and light up to signal breaking (Lumos, 2020).

After Lumahelm, we turned to eBikes: first, because worldwide use is rising (Intelligence, 2019); and second, because bikes with electric engines offer novel opportunities for integration, we believed. We found that eBikes are easily accessible, comparatively affordable devices with which researchers can explore bodily actuation as part of an integration experience that goes beyond visual representation as in Lumahelm. In particular, we found that the proliferation of eBikes is changing the global transportation and leisure landscape, creating opportunities for bike riders to go further and faster and for people to take up cycling eBikes for transportation offer sustainability benefits and open new social cycling experiences, contributing to an emerging global phenomenon of cities working to have more bike riders. As such, we became interested in a more profound understanding of how humans and electric bikes could become "somatokýklos" where the rider and the bike become one entity. Somatokýklos comes from the Greek "σώμα" (sóma) + "κύκλος" (kýklos) = "σωματοκύκλος" (somatokýklos) to describe a person who has a very close relationship with their bike, as if their body and the bike were one entity. As such, we asked what type of experiences we could strive to design for, how could we make this fun, safe, and sustainable, and how we ultimately might contribute to shaping the global cycling phenomena. Our research aimed to contribute to this understanding by studying the user experience resulting from the somatokýklos rider-machine merger.

We describe our three eBike explorations below.

4.2. *Ava, the leaning eBike*

Ava, the "leaning eBike" (Andres et al., 2018) (Figure 2), helped us explore how sensors on the user's body can support the integration experience. We noticed in prior work (Andres et al., 2016) that riders (like participants in other sports) commonly lean their bodies forward to embrace speed when riding. Ava senses when the rider leans forward when riding and increases engine support. The extent and length of the lean determine the engine support intensity.

Leaning to increase engine support differs from most current eBikes practices, for which input is sensed via the pedals or a throttle on the handlebar. In contrast, we strapped a mobile phone tightly around the rider's chest. The phone's gyroscope senses the rider's upper body posture and sends this information wirelessly to an Arduino, which talks to the electronic control unit and adjusts the engine support.

We conducted a study (Andres et al., 2018) with 22 eBike riders. 10 of these riders self-identified as female, 12 as male (none as "other" or self-prescribed). They were between 24 and 55 years of age, with the average age being 36 years. We recruited them through e-mails and advertisements. 7 participants came from the university, 8 from the local council and 7 from colleagues. 10 of them had 3–6 months, 7 participants 7–18 months, and 5 participants 19–36 months eBike experience.

Overall, the interviews with the participants suggested that posture-sensing appeared to support the integration experience. In particular, participants made interview statements such as "I felt like

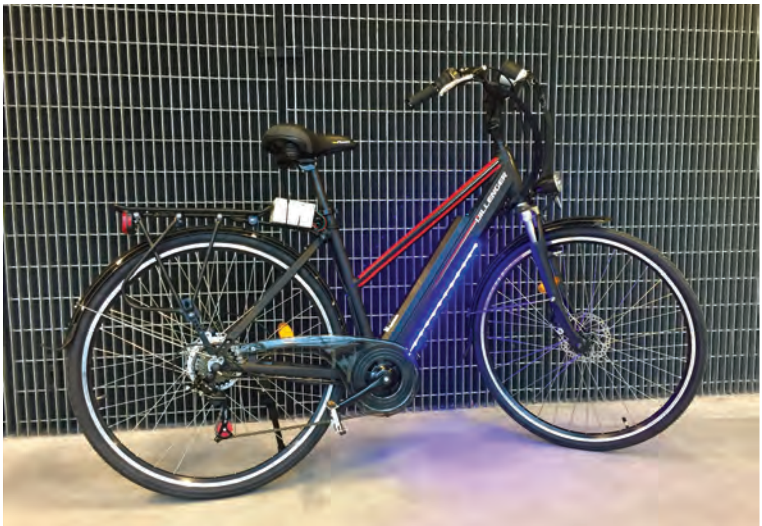

Figure 2. Ava, the "leaning eBike"

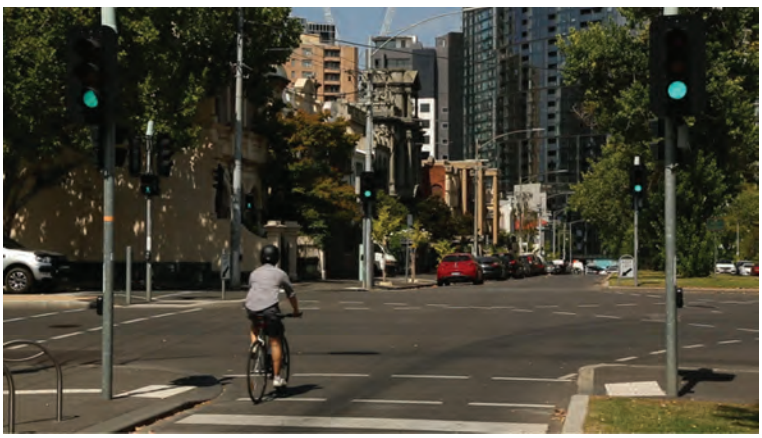

Figure 3. Ari, the "lights eBike"

a superhero" as they experienced the support not as coming from an external device, but as a product of the integrated human-machine system. It seems that participants felt this power to be their own.

4.3. *Ari, the lights eBike*

Ari, the "lights eBike" (Andres et al., 2019) (Figure 3), helped us explore if, and how, sensing external data can support the integration experience. Ari uses traffic light data and the rider's speed to increase engine support as a way to help the rider to maximize the number of lights caught on green. Our local city traffic authority centrally controls all traffic lights, and we make this traffic light data available to our system. A mobile phone is used to sense the bike's speed, which allows to calculate how far the rider is away from the next lights and provide more engine support if needed so that the rider is able to arrive at the lights when they are turning green.

A study (Andres et al., 2019), with 20 riders (6 female, 14 male, between 23 and 48 years, average 36 years), suggested that the rider and the eBike engaged in a partnership. For example, in the interview, one participant said: “It’s like your buddy, it knows where the traffic lights are at, but it doesn’t have eyes. You have eyes, so you’re like, ‘I’ll take care of you. You take care of me,’ so, ‘You do the traffic light thing. I’ll make sure we don’t hit anything’.” This speaks nicely to our notion of both the conscious and subconscious being involved in bike riding; here, participants noticed that this could be shared with a system. Another quote was: “The bike is not actually capable to determine if it’s dangerous ahead or not. Actually, you, as a human, you are equipped with those sensors. The bike has some information that you don’t have, and you have the information that the bike doesn’t have.” This quote highlights for us that participants can appreciate if a system shares aspects of the conscious and subconscious if there is a value-add to their experience. Another participant described how “it felt like a guided bike riding, like the bike was my teacher almost.” This quote suggests that an integration experience can range from an almost completely subconscious experience to one where the computational machine is taking a more active, conscious role that functions almost as a teacher, guiding the experience. Another participant compared it to riding a horse, harking back to the horse riding HCI study (Höök, 2010) mentioned in related work: “It can sense things that humans can’t.”

4.4. *Ena, the EEG eBike*

With our third eBike, Ena the “EEG eBike” (Andres et al., 2020) (Figure 4), we explored how an electroencephalogram (EEG) can support the integration experience. A state of peripheral awareness is associated with better athletic performance, coordination and awareness of the environment (Lemmink et al., 2005; Nan et al., 2013, 2014). We used an EEG cap to sense neurological activity

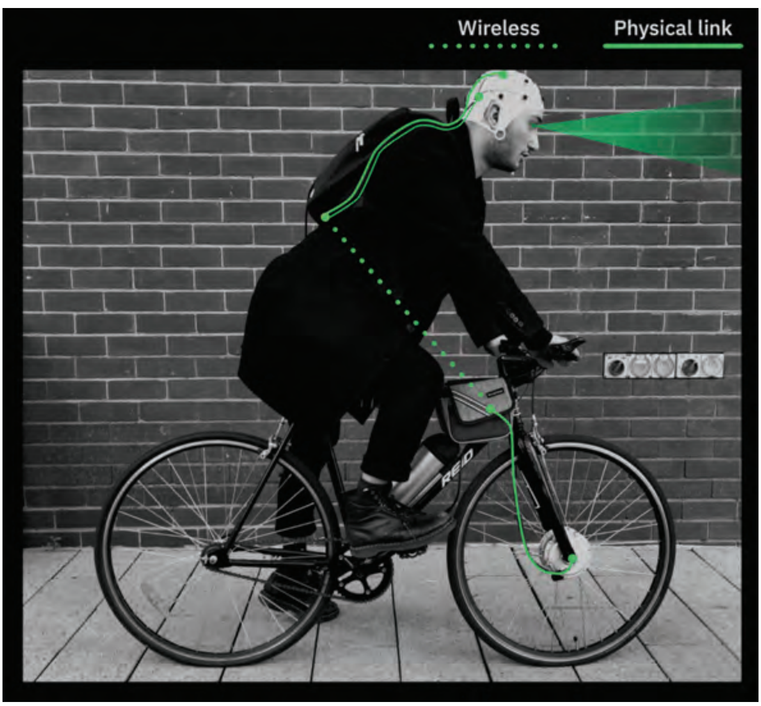

Figure 4. Ena, the EEG eBike.

in relation to the rider's field of view, indicating the rider has reached a state of peripheral awareness, and prompting the provision of engine support. For safety, we included a sensor that picked up when the rider engaged the brakes and cut off the eBike's engine regardless of EEG state.

A study (Andres et al., 2020) with 20 riders (8 female, 12 male, between 24 and 58 years, average 40 years) suggested that the EEG functionality supported bike and rider integration. For example, in the interview, one participant said the following: "It was coming from my brain wave, but the system could slow down before I could act on [sic] to 'hit the brakes', it was uncanny but useful." Another quote was: "The bike is trying to ensure that I'm in sync with myself and my own thoughts, using my signals." This quote around "being in sync" highlights for us that an integration experience can be not just about being integrated with a computational machine but also about being integrated with oneself, which we find intriguing, as this might suggest that integration systems could also help people be more in sync with themselves. Another participant said: "It felt like the bike was drawing upon my perception of how safe the way ahead was." This speaks nicely to our intention of enhancing the rider's subconscious abilities, here, the ability to sense the road ahead, but not just consciously, but subconsciously as determined by the field of view. It appears that the result is a seemingly enhanced subconscious self.

5. Approach to arrive at the themes

Our approach to arrive at the themes was informal to facilitate open discussions that could also cope with critique amongst ourselves. We did not set ourselves a time limit or deadline in order to allow all of us enough time to express what they wanted to say. We aimed to respond in an agile manner to let the themes evolve organically.

As part of our practice, we used discussions around prior work and reflections on our own design practice as well as having conducted associated studies, in order to arrive at our themes. This involved iterating between theory and practice quite extensively. This means that we did not begin with a particular theory. This also means that we also did not aim to refute a specific theory. Instead, we wanted to let theoretical design understandings emerge organically as part of the overall design process.

Such an approach has practical strengths, for example, the ability to generate vivid descriptions that practitioners might be able to readily grasp, but also weaknesses, such as limited opportunities to replicate how the strategies emerged (Benford et al., 2005; Mueller et al., 2014, 2020). Nevertheless, this approach has already successfully resulted in design themes for similar application domains concerned with the coming together of interactive technology and the human body (Benford et al., 2005; Mueller et al., 2014, 2019, 2020, 2020), and hence we believed that it could be equally beneficial in this instance.

To facilitate our process, we engaged whiteboarding sessions and thinking-through-writing, where we collaboratively wrote in shared online documents. This included discussions around our personal experiences, both from the design process but also personal bike journeys. The goal was to develop more abstract concepts that could help grow larger groupings. These larger groupings were then used to dive deeper and express some of our thinking in more detail. We also checked if there were any overlappings across these groupings and tried to consolidate them. This also included clustering exercises in order to arrive at an (in our understanding) manageable number of themes that would comfortably fit within the typical length of an HCI article. With our themes, we tried to be both comprehensive and succinct.

All activities were captured in a shared online drive. The drive also contained the final write-up text that formed this article to which everybody had equal write and edit access. The content of this shared drive formed the basis for this paper.

It is acknowledged that our approach was discursive and informal, speaking to the dynamic process that led to our bike systems. As we had expertise on thematic analysis, the approach borrowed from its goal to develop themes, which we present in this article. However, no formal tools such as NVivo were used. The main text was developed through a process in which the authors build on each other's writing, similar to prior work that also analyzed data from multiple prior design examples (Bowers, 2012; Gaver & Bowers, 2012; Mueller et al., 2017, 2018, 2020, 2020, 2020). As such, our work speaks also to the designerly approach of generating abstract knowledge through examples as put forward by, for example, prior work on annotated portfolios (Bowers, 2012; Gaver & Bowers, 2012) or the technology futures approach (Mueller et al., 2022).

Of course, we acknowledge that other approaches to arrive at the themes are possible. We therefore encourage such future work that could complement our article by using more established and structured approaches such as proposed in prior work on strengthening qualitative research (Gunawan, 2015; McDonald et al., 2019; Muller & Kogan, 2010; Shenton, 2004).

Although our approach has limitations (such as a limited perspective, discussed in "Limitations and future work"), it also has advantages. In particular, we point out that one of the strengths of our article is that our themes speak to our design practice of having developed a range of bike systems ourselves, rather than, for example, having outsourced their development to an outside party, as such, they reflect a personal involvement that allows speaking from the "trenches" of a design research lab. This allows to reveal insights that other authors might not necessarily have access to.

Furthermore, we believe that our approach has practical strengths, for example the ability to generate vivid descriptions that practitioners might be able to readily grasp; however, it is acknowledged that this also comes with weaknesses, such as limited opportunities to replicate our approach (Benford et al., 2005; Mueller et al., 2014, 2020). Nevertheless, this approach has already successfully resulted in themes for similar application domains concerned with the coming together of interactive technology and the human body (Benford et al., 2005; Mueller et al., 2014, 2019, 2020, 2020), and hence we believe that it might be beneficial also here.

Taken together, we believe that our work has value as it allows for an initial starting point for future work that aims to move our understanding of how to design integration experiences forward as a whole.

6. Themes for designing integration systems

We now describe a set of themes that designers might want to consider when designing future integration experiences. These themes are, of course, not exhaustive. They are, rather, a starting point for future research; emphasizing what we have learned about integration from prior work and through our research-through-design processes. We note that not all our bike systems implement all themes, nor is this necessary. We have qualitative statements from some of our studies that we use as indicators for our themes, however, we acknowledge that further studies and evaluations could provide additional evidence. For now, the themes serve as foundation through which we can discuss our theoretical thinking and suggest improvements; practices which are consistent with the research-through-design tradition (Gaver, 2012; Gaver & Bowers, 2012).

At the end of each design theme, we also present implementation opportunities for consideration based on our design practice as was done in prior work that aimed to guide designers through a portfolio of examples (Mueller et al., 2018). These implementation opportunities in the form of "Consider … " respond to colleagues' previously articulated desire for more design guidance in HCI (Höök & Löwgren, 2012). We point out that these opportunities are not guaranteed to be successful, nor are they exhaustive, others might be possible. Furthermore, although grounded in design work and studies, they have not been evaluated in external studies, hence for additional proof, such as quantitative evidence, future research is needed.

We structure our design themes based on whether they aim to facilitate a transition between the conscious and subconscious self or engage the subconscious self. As prior HCI work has discussed extensively how to support the conscious self (including within bike work (Rowland et al., 2009)), we focus here on the subconscious self and its transitions for now and leave

Table 1. Design themes.

Conscious/ subconscious	Design theme	Implementation opportunities
Transition to the subconscious self	*Employing conceptual aids for the transition to the subconscious self*	Consider not just visuals, but also other sensory modalities such as auditory when designing conceptual aids to reinforce the transition to the subconscious self. Consider aligning digital content (such as enabled by AR) as a way to help reinforce traditional conceptual aids of becoming "one" with the computational machine. Consider learning from game designers' expertise around imaginary and fantasy worlds when it comes to creating "nonsensical" and "unrealistic" conceptual aids to reinforce the transition to the subconscious self. Consider the use of technology as a way to create accompanying, not just preparatory, conceptual aids to reinforce the transition to the subconscious self.
Transition to the subconscious self	*Facilitating sensory-motor couplings for the transition to the subconscious self*	Consider existing movement interactions as a way to facilitate sensory-motor couplings, making use of the potential of sensors that capture bodily movement. Consider biosensors as a way to facilitate new sensory-motor couplings.
Transition back to the conscious self	*Managing controlled and uncontrolled flow*	Consider making use of sensors that can detect external dangers to allow to interrupt the flow state by bringing the conscious self to the fore as a way to manage uncontrolled flow. Consider progressively adjusting a user's perceived challenge during non-engaging activities by adding, for example, virtual challenges for supporting controlled flow.
Engaging with the subconscious self	*Supporting evidential experiences that engage the subconscious self*	Consider technology to alter existing evidential experiences but provide users with opportunities to adjust to the altered experience. Consider enabling new evidential experiences by employing sensor data that users can subconsciously engage with.
Engaging with the subconscious self	*Managing human and machine agency shifts*	Consider that increasing a machine's level of agency comes with the potential to interrupt the subconscious self and therefore needs to be carefully designed. Consider that it might be necessary to spend significant time to fine-tune the extent as well as the gradient of the machine's agency if the goal is to not interrupt the subconscious self.

additional design themes for future work. We first begin with an overview of all design themes and their categorization including their implementation opportunities in a table form before we explain them in detail (Table 1).

6.1. *Employing conceptual aids for the transition to the subconscious self*

This theme highlights the opportunity to facilitate integration by using conceptual aids to help the transition of bodily actions to the subconscious self. Conceptual aids might be familiar to interaction designers for their design work. Here, in contrast, we are referring to conceptual aids to be employed by users for the transition to the subconscious self. A conceptual aid, which has been used in motorbike training to help riders become "one" with the bike, is an image or idea that improves a bodily action or makes the action easier to perform by calling upon a particular feeling (Eberspächer, 1990; Spiegel, 2019). Conceptual aid is the translation of the German "Hilfsvorstellungen," literally "helping imaginations." The purpose of a conceptual aid is to elicit certain feelings, and by clarifying these particular feelings in the body, to habituate the corresponding bodily action. As such, a conceptual aid aims to encourage what was originally in the domain of the conscious self to transition or "sink in" to the subconscious self (Spiegel, 2019).

An example of a bike conceptual aid involves the stationary rider trying to imagine they are "flowing" ever more deeply into the bike; all the way down into the contact patches of the tires (Spiegel, 2019). The aim is to facilitate a particular kind of physical feeling that, ideally, provides a large amount of information on traction limits when riding (Spiegel, 2019). Another example is the phrase "don't sit on the bike, sit in it" that aims to remind riders of a particular feeling for which they should be aiming (Spiegel, 2019). Interestingly, mental training (commonly part of training) usually involves a realistic conception of the execution of an action. In contrast, conceptual aids are often unrealistic and sometimes nonsensical (Spiegel, 2019).

We believe that the notion of conceptual aid applied to especially our leaning and EEG eBike systems, both as support for integration with the bike ("flowing" into the bike) and as support for integration with the systems' interactive components.

Participants of the leaning eBike study enjoyed the superhero experience the bike provided, suggesting that this feeling could be considered in the development of a conceptual aid. For example, before riding, participants could be told to "imagine being a superhero," having superpowers thanks to the eBike, and "flying forward." Furthermore, we also note that the "woosh" sound we implemented to play through a speaker, attached to the handlebar, when the rider leaned forward, could be seen as functioning as a conceptual aid. This conceptual aid would stand in contrast to conventional participant instructions, such as: "If you bring your upper body forward, the engine support will be triggered." We believe that this conceptual aid allowed focusing on a particular, "unrealistic" feeling, rather than a specific command, as a way to facilitate a transition from the conscious to the subconscious self and hence could support integration.

The EEG eBike inspired us to consider conceptual aids regarding peripheral vision, such as "imagine you have superhero vision that broadens your field of view." This might help participants to deliberately engage the subconscious self when riding, become more aware of their surroundings, and improve their safety.

Our findings from our design work and associated studies relating to conceptual aids highlight, for us, the potential of interactive technology to complement traditional, "analog" concepts and images as conceptual aids; for example, see the "woosh" sound of our leaning eBike that could be regarded as an auditory, not visual, conceptual aid.

As such, we suggest to designers to consider not just visuals, but also other sensory modalities, such as auditory, when designing conceptual aids to reinforce the transition to the subconscious self.

Furthermore, our work on Lumahelm highlights, for us, the potential to use interactive visuals as conceptual aids. For example, we can envision the use of augmented reality (AR) as conceptual aid for integration, such as an AR helmet that allows riders to see their own bodies (when looking down) "flowing" into the bike, resulting in an interactive version of the traditional conceptual aid of "flowing" ever deeply into the bike as mentioned above. Therefore, we suggest to designers to consider aligning digital content (such as enabled by AR) as a way to help reinforce traditional conceptual aids of becoming "one" with the computational machine.

In addition, because game designers are well versed in creating digital content around imaginary and fantasy worlds (Salen & Zimmerman, 2003), we believe that interaction designers could draw from their expertise when aiming to create "nonsensical" and "unrealistic" conceptual aids to reinforce the transition to the subconscious self.

Furthermore, we believe that interaction designers have the opportunity to create engaging accompanying (Spiegel, 2019) conceptual aids that support the bodily action while it occurs, in contrast to most traditional (analog) conceptual aids that are used in preparation. Therefore, we suggest designers to consider the use of technology as a way to create accompanying, not just preparatory, conceptual aids to reinforce the transition to the subconscious self.

In summary, based on the theoretical work on conceptual aids and combined with our insights from our design work and associated studies, this theme highlights to designers that they can consider facilitating integration by using conceptual aids to help the transition of bodily actions to the subconscious self. Our craft knowledge helped us identify a couple of implementation opportunities that designers have to their perusal when aiming to utilize interactive technology to create conceptual aids for future integration experiences. They do not guarantee results (as we have not yet implemented all of them), however, should be valuable starting points that could be useful for designers who are seeking guidance where to start when it comes to creating conceptual aids for integration.

6.2. *Facilitating sensory-motor couplings for the transition to the subconscious self*

This theme highlights that designers can consider facilitating sensory-motor couplings as a way to help transition bodily actions to the subconscious self. The term "sensory-motor" refers to a course of bodily actions where sensory and motor processes are intertwined in a tight "back-and-forth" relationship, such as braking to arrive at a white line before a set of traffic lights (very different to, for example, a traditional button press interaction that only allows for a binary on/off, i.e. the equivalent here would be a switch that engages the brakes at their maximum power). The braking force created by the motor process is constantly compared and weighted by sensory input against the speed and position of the bike relative to the white line, and the amount of braking pressure is correspondingly adjusted. In other words, there is continuous feedback occurring during the entire course of action, and this requires constant adjustment to bring the expected and received feedback into the closest possible alignment (Spiegel, 2019). Users not only need to practice the sensory component (a sufficiently precise expectation, reception and interpretation of the feedback) but also the motor component (Spiegel, 2019).

Previous HCI work has highlighted the potential of considering a sensory-motor coupling (van Dijk et al., 2014), and there are examples of interactive systems supporting it (Stienstra et al., 2011). Here, we extend this prior work by highlighting the potential of facilitating sensory-motor couplings for the transition to the subconscious self in integration experiences.

The leaning eBike replaced a traditional eBike-control lever (using interval settings) with a sensory-motor coupling integrated with the leaning-forward action. Participants received ongoing auditory feedback through increased engine sound, the visual sense perceived the speed of the environment passing by, the kinesthetic sense detected acceleration, and the tactile sense noticed more headwind on the skin. We believe that this sensory-motor coupling contributed significantly to the positive integration experience. As such, we suggest to designers to consider existing movement interactions as a way to facilitate sensory-motor couplings, making use of the potential of sensors that capture bodily movement.

Furthermore, we argue that the leaning eBike utilized an "ongoing action" (leaning forward is inherent to cycling) versus a "special action" that users need to be informed about specifically. We introduce this vocabulary ("special action" and "ongoing action") from game design (Fullerton et al., 2004) to the design of integration experiences.

In hindsight, we believe that we could have facilitated additional sensory-motor couplings. In particular, we believe that biosensors (capturing, for example, heart rate or glucose levels) have potential to establish new sensory-motor couplings where actuation is in (or near) real-time reflective of sensor data, for example see the heart rate eBike that provides engine support based on the rider's heart rate data (Mannion et al., 2019). As such, we suggest to designers to consider biosensors as a way to facilitate new sensory-motor couplings.

In summary, this theme highlights to designers that they can consider facilitating sensory-motor couplings as a way to help transition bodily actions to the subconscious self.

6.3. *Managing controlled and uncontrolled flow*

This theme highlights that designers can consider facilitating integration by engaging the subconscious self for "controlled flow;" this should be done in concert with bringing back the conscious self when needed to reduce the dangers of "uncontrolled flow." Flow is the mental state of effortless attention, in which a person is completely absorbed in performing an activity (Csikszentmihalyi, 1990). People are most likely to enter this flow state, often called being "in the zone," if there is a good balance between perceived challenge and perceived skill (Csikszentmihalyi, 1990). Examples of this condition can be drawn from different activities such as video gaming (Chen, 2007; Sweetser & Wyeth, 2005) and sports (Jackson & Csikszentmihalyi, 1999), including bike riding (Rheinberg, 1991, 1996). Experienced motorcyclists have described it as an exhilarating condition of floating (reminiscent of Csikszentmihalyi's water metaphor (Csikszentmihalyi, 2000)), which is amplified by the disinhibition through speed (Spiegel, 1953), and enhances riding's appeal (Spiegel, 2019). Spiegel characterizes this flow as "controlled flow" that is monitored and mastered (Spiegel, 2019). Conversely, in risky sports, "uncontrolled flow" hides dangers (Rheinberg, 1996). A person's conscious self narrows its focus as successful actions and positive feelings signal that they are doing the right thing, calling for more of the same, despite those actions carrying increasing risks. Consequently, we extend prior HCI work on mostly only the positive effects of controlled flow (Knaving et al., 2015; Martin-Niedecken & Götz, 2017; Sinclair et al., 2009) by highlighting that when it comes to integrated experiences we need to consider the danger of uncontrolled flow preventing the conscious self's ability as warning indicator that a person engaging the subconscious self is suppressing.

We found that our Lumahelm's playful design exhibits affinities with videogames. Our participants reported that they used their gears to find a good balance between perceived challenge and perceived skill by playing a game of trying to keep their heart rate at a specific value. This suggests, to us, that participants used the system (in particular the gears) to find their flow state. As noted above, this flow state could lead to an ignoring of the conscious self (uncontrolled flow) that could warn of dangers, both externally (a pedestrian crossing the road) but also internally (heart rate too high, for too long). With the benefit of hindsight, we should have implemented a warning system that, for example, sensed if the heart rate was at dangerous levels for too long, and provided auditory feedback or similar to alert the suppressed conscious self in order to allow returning from uncontrolled flow back to controlled flow.

Riders in the leaning eBike study said that they found the sweet spot between perceived challenge and skill. The ability to go faster through leaning seemed to contribute to this outcome, as it provided the ability to change the challenge level easily, and more easily than without the engine support.

Participants in the lights eBike study reported that sometimes the bike surprised them with an acceleration that was faster than they thought appropriate to the situation (say, there were too many road users nearby). Here, the rider was pushed out of their controlled flow zone into uncontrolled flow and had to engage the conscious self to correct the speed. We could have addressed this situation, for example, by mounting a camera on the handlebar facing forward to sense external dangers to inhibit such surprising acceleration to keep riders in controlled flow.

Our EEG bike riders' comments suggested flow, as they often compared the experience to videogames. As just one of the examples, a rider said: "In an action-adventure game there are non-playing characters, you can choose to interact with them or not, in this case those characters were the other riders and pedestrians because I could choose to negotiate a way with them to go through – my goal was to get rid of the obstacles so that I could get the system to accelerate again". It appeared that the technology supported engaging the subconscious self for controlled flow, while the eBike augmentation contributed to it not turning into uncontrolled flow.

By looking at our design journey, we believe that there is an opportunity to progressively adjust a user's perceived challenge during non-engaging activities (for example dull stretches of a road) by supporting them with game challenges (for example projected virtual obstacles (Tan et al., 2015)) to support controlled flow. As such, we suggest designers to consider progressively adjusting a user's perceived challenge during non-engaging activities by adding, for example, virtual challenges for supporting controlled flow.

Furthermore, designers could support the subconscious self to facilitate entering a controlled flow state through allowing for an enlarged perceived challenge range. Any uncontrolled flow state could be interrupted by bringing the conscious self to the fore (for example, through an alert) when sensing external dangers. Therefore, we suggest designers to consider making use of sensors that can detect external dangers to allow to interrupt any uncontrolled flow state by bringing the conscious self to the fore as a way to help people return to controlled flow.

6.4. *Supporting evidential experiences that engage the subconscious self*

This theme highlights that designers can consider facilitating integration by supporting evidential experiences that engage the subconscious self. Spiegel (2002) describes an "Evidenzerlebnis," translated as "evidence experience" (Spiegel, 2019), but we prefer "evidential experience:" a spontaneous insight into a situation, independent of rational or intellectual considerations – hence in the domain of the subconscious self – along with certainty that the insight is correct. The notion of evidential experience is particularly pertinent in sports, where fast motor actions are needed. Evidential experiences are a domain of the subconscious self; mostly preceding motor actions and not requiring conscious thought.

When it comes to riding, a dominant evidential experience is the ability to handle a lean angle. Through evolution, humans have come to "know" subconsciously that, beyond a 20-degree lean, the danger of losing traction on a surface increases quickly. Therefore, when going into a curve or along a steep slope, the subconscious self watches over the rider, preventing them from leaning further without conscious involvement or even knowledge about the angle value. However, in order to exceed the 20 degrees, which is important for cyclists (who might go beyond 45 degrees (Witts, 2019)) and especially motorcyclists (going up to 60 degrees (Allain, 2015)), the technical conditions are not the only limitations. The rider needs to practice engaging their conscious self in order to exceed the 20 degree preset (Spiegel, 2019). The next step is then to "internalize" this leaning, turning this new experience into one belonging to the subconscious self, so the rider can concentrate on other aspects of the ride (Spiegel, 2019).

While we believe that the Lumahelm did not engage with any evidential experience besides those already present with riding, the leaning eBike used the digital component to alter the evidential experience riders have when leaning forward. Leaning makes the silhouette of the rider smaller, reducing air drag, and enhances speed. This effect was amplified through the system simultaneously increasing engine support. In fact, the digital component of the system appeared to initially result in an experience that did not match with the rider's existing evidential experience. Consequently, riders needed a couple of rides in order to adjust their evidential experience and incorporate into their subconscious self the relationship between lean and speed outcome. As such, we suggest designers consider technology to alter existing evidential experiences but provide users with opportunities to adjust to the altered experience.

With the EEG eBike, the system "hooked" into the rider's evidential experience of reduced field of view as a result of perceived danger and made this information available to the bike to stop engine support in order to keep the rider safe. The positive feedback from our study participants suggested to us that there is potential to support evidential experiences through additional sensors that capture bodily data. For example, we could envision a system that senses power meter data and makes this continuously available to the user. This could be achieved through novel output modalities, such as heating pads embedded in clothing (as previously suggested (Li et al., 2018, 2019)). This might allow for a subconscious engagement with that data, enabling a "first-person feel" (Svanæs, 2013) for such power meter data that could be used to let an optimal training zone value "sink in." Therefore, we suggest designers consider enabling new evidential experiences by employing sensor data that users can subconsciously engage with.

6.5. Managing human and machine agency shifts

This theme highlights that designers can consider facilitating integration by designing for the subconscious self's role in managing human and machine agency shifts. Shared agency between the computational machine and the user can play a key role in integrated systems (Mueller et al., 2020), and shifting the balance of shared agency needs to be carefully designed in consideration of the subconscious self. The sense of agency has been described as the experience of initiating and controlling an action ("*I am the one who is in control of this car*") (Braun et al., 2018), and the conventional view is that it is beneficial for integration if the user has full agency, especially through the subconscious self. For example, a rider losing control over their bike would be considered a point of dis-integration (Spiegel, 2019). We extend prior HCI work (Bergstrom-Lehtovirta et al., 2018; Kasahara et al., 2019; Limerick et al., 2014) on agency and integration experiences by pointing out that technology advances, such as machine learning, allow for novel and interesting ways to share agency between user and machine (Allen et al., 1999; Horvitz, 1999). Examples include drive assistant systems, as well as automatic emergency brake systems that brake "for" the user to avoid an accident. These systems are becoming increasingly commonplace in motorbikes, and even eBikes, which suggests that rider and bike agency will undergo significant change. We note that the sense of agency plays out differently when it comes to the conscious self and the subconscious self, and designers should take this into account when aiming to design for integration. On the one hand, systems that take control can enhance safety. These systems are useful when riders engage their subconscious self to ride while engaging their conscious self in some other activity (talking to a fellow rider). If danger arises, bringing the conscious self to the fore to respond can take too much time, so the system might take control to respond more quickly. Our EEG bike is a good example of this support. We considered whether we should go one step further with the EEG bike and not only stop engine support upon sensing a reduced field of view, but also trigger the brakes, and decided that if the system took over too much agency, especially when the user is engaging on a conscious level, this could be experienced as the rider losing control (feeling like a passenger) and hindering integration (Spiegel, 2019). As such, we suggest designers consider that increasing a machine's level of agency comes with the potential to interrupt the subconscious self and therefore needs to be carefully designed.

We experimented extensively to get the leaning eBike engine support right (both the degree of support and having the support rise gradually so as to feel like a "smooth" transition), so that riders, especially when engaging their subconscious self, did not "notice" that the engine supported them when they leaned forward. If the engine transition produced a noticeable "jerking" sensation, we observed that the conscious self was immediately brought to the fore, hindering integration. Consequently, we believe that any shift in agency needs to be carefully managed in order to not endanger any potential for integration.

Our lights eBike participants reported that, once the engine support kicked in, they realized they needed to pay more attention, suggesting that their subconscious riding turned into a more conscious experience as a result of the shift in agency. We could have also removed any agency from the bike by mounting a display on the handlebar that shows the rider the next traffic light's changing pattern, indicating whether to go slower or faster to make the next green light. Rider agency would increase, but the experience would likely demand more conscious attention.

We see as an opportunity here to fine-tune the extent as well as the gradient of the machine's agency to not interrupt the subconscious self. However, this fine-tuning will take time. We, therefore, suggest designers to consider that it might be necessary to spend significant time to fine-tune the extent as well as the gradient of the machine's agency if the goal is to not interrupt the subconscious self. For this, it would help to know whether the user is engaging the subconscious self at any point in time. However, there is no foolproof way to check if the subconscious self is engaged; we could envision employing EEG to gain indicators, while we also point out that other researchers have attempted to engage the user in a conversation (as used in bike and horse riding (Höök, 2010)) to identify where the user's conscious attention lies.

7. Limitations and future work

Our work has only scratched the surface of discussions on the conscious and subconscious self within human-computer integration. There remains much to explore, including, for example, what insights prior theories such as phenomenology (Svanæs, 2013) offer into user experiences of transitions between the conscious and subconscious self, or how users' sense of bodily ownership, important for integration (Mueller et al., 2021), varies with changes in their conscious and subconscious levels of engagement (Braun et al., 2018).

We also acknowledge that we come from a WEIRD (Western, Educated, Industrialized, Rich, and Democratic) society (Henrich et al., 2010) and bring a particular perspective to the table. We encourage other researchers from other societies and backgrounds to strengthen the value of our work by challenging, discussing, and refuting some of our integration experiences.

We have also not yet explored integration systems with human bodies that are beyond a culturally understood "norm," such as people with temporary or permanent disabilities. We believe that our work can make a contribution in these contexts through, for example, exploring integrated rehabilitation system design. We also hope that our work on bodily actuation inspires further investigations into the safety and in particular ethical aspects on machines controlling humans, hopefully advancing the ethical discourse on the human-computer integration paradigm.

We also acknowledge that the durations of our studies were rather short and hence we have not been able to examine much how integration occurred over time. Hence, this is a limitation of our work. Future work could investigate more long-term studies to examine any integration that might occur over time. We believe that our work might be useful in structuring such long-term studies.

We also acknowledge that, as our work is only an initial starting point toward actionable suggestions, our implementation opportunities can be seen as obvious design considerations. However, we argue that our research still has value as it, to our understanding, is the first to articulate these suggestions that designers, including those new to the field, might easily miss. Furthermore, our work offers designers a list of implementation considerations that they could use to go through, providing an opportunity to check if they have covered all the (albeit seemingly obvious) considerations when designing for "becoming one with the machine."

Finally, we acknowledge that we have not yet fully considered social aspects when integrating the human body. Indeed, advances in networking technology allow to envisage the potential for systems in which integration does not occur just between one human and one machine, but between one machine (or more) and multiple people.

8. Conclusion

Technological developments and the emerging human-computer integration paradigm have advanced design work at the intersection of interactive technology and the human body, leading to innovations that fuse the human body and the machine into systems that are more advanced than the sum of their individual parts. And yet, recent scholarly work suggests that HCI has only just begun to fully understand the design of such integration systems. To advance the field, in this article, we offered insights from prior (non-HCI) work on bike riding and articulate how an integration experience could benefit from design that engages both the conscious and subconscious self and especially the transitions between the two. To support work consistent with this approach to human-machine integration, we present a set of themes to aid the design of future integration systems, and we discuss them with reference to four of our own bike design explorations. While our results do not present a complete understanding, we hope they serve as a springboard for future investigations.

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