Integrated Exertion – Understanding the Design of

Human–Computer Integration in an Exertion Context

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and ethics procedures and guidelines have been followed. I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

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Abstract

Researchers in human–computer interaction (HCI) are increasingly exploring how to support the exerting user through interactive technology. To date, most assistive systems have focused on sensing and presenting information to the user during the experience. Recently, due to advances in technology, systems can sense, interpret and automatically act on information, giving the system the opportunity to act on the experience alongside the user without needing user input. These advancements offer the opportunity to design human–computer integration, where the user and the system work in a partnership. The gap in knowledge today is that there is limited design knowledge for designing human–computer integration experiences in an exertion context. To explore this gap, I conducted three experiments by building three eBike systems, because eBikes allow the user to invest physical effort as part of an exertion experience and eBikes can be easily modified to study different forms of integration with the exerting body.

In Case study one, I created an eBike system that used the user's movement data to synchronously increase engine support as the user moved, offering the user the sensation of having extra physical strength that was controlled with their body. This resulted in design knowledge to design superpower-like integrated exertion experiences. In Case study two, I created an eBike system that used traffic light data to facilitate user–system co-operation to cross traffic lights on green, where the user could gain physical support to go faster and also gain increased sense-making in relation to the changing traffic light patterns. This resulted in design knowledge to design user–system co-operative-like integrated exertion experiences. In Case study three, I created an eBike system that used the user's physiological data via electropherogram to monitor neurological activity in relation to the user's field of view, reaching peripheral awareness to regulate engine support. This resulted in design knowledge to design symbiotic-like integrated exertion experiences.

By building, studying and publishing each system and consulting with my group, I began iterating and refining the framework for designing integrated exertion. This framework presents the intersection of two dimensions; the first dimension is: 'The type of support offered', on one end of this dimension *to extend the user's abilities* and on the other end *to challenge the user's abilities*. The second dimension is: 'The degree of control the user has over the system', on one end of this dimension *to cause momentarily loss of bodily control over the system* and on the other end *to support maintenance of bodily control over the system*. This intersection revealed

four key areas and twelve integrated exertion user experiences to further the general HCI understanding of designing integrated exertion experiences.

My intention with this work is to promote a future with exertion experiences through a human–computer integration approach to explore how technology can extend the user's abilities to enable engaging experiences.

CHAPTER 1

Introduction

Discovering integrated exertion.

CHAPTER 1 – Introduction

In this chapter I outline my research topic, present the research question and discuss the approach for the rest of the thesis.

Introduction

Supporting the physically active human body through technology has been a consistent area of research in human–computer interaction (HCI), due to the joys of movement and many health benefits that it can offer (Mueller et al., 2017; Kunze et al., 2017; Hämäläinen et al., 2015; Isbister, 2013; Marshall et al., 2011). As HCI practitioners study innovative ways to support the exerting body, interactive systems have evolved from screen-based interactions to devices such as the Kinect and Wii (Isbister, 2013), which allow users to use bodily movement to interact with digital content while engaging in an exertion experience. This is a step forward in supporting the exerting body, but it comes with some limitations; for example, the user has to remain within the field of view of the device (in the case of the Kinect) and this means that they are constrained to a location and a screen for interaction. This limitation has inspired the field to explore means of supporting exerting users in the outside world without screens, turning the physical world into the space where the interaction between the user and the interactive system occurs (Mueller, 2017). To further this vision, HCI practitioners are exploiting advances in computing, such as the internet of things (Swan, 2012), to leverage devices that work wirelessly, are portable and move closer to the body from which the interactive system can sense information. Moreover, HCI practitioners are also leveraging algorithms (Dasgupta, Papadimitriou, & Vazirani, 2008; Schirner, Erdogmus, Chowdhury, & Padir, 2013) to interpret the sensed data through a programmatic approach in order to inform how the interactive system should respond.

These advances create an interesting opportunity to design interactive systems that can act on the experience alongside the user, to support them without being constrained by a screen or location. Interestingly, this means that these systems do not require user input to generate an output as they can be constantly sensing and interpreting data to support the user. Farooq and Grudin (2016) suggest that these advances apply to how we design interactive systems to act on the experience and are extending the interaction paradigm from HCI to human–computer *integration*, where 'Integration implies partnership ... Partners construct meaning around each other's activities, in contrast to simply taking orders. They are co-dependent, drawing meaning from each other's presence' (Farooq & Grudin, 2016).

This emerging area of human–computer integration offers untapped opportunities for HCI practitioners, especially in an exertion context. So far, there is limited design knowledge on how to analyse and design interactive systems that offer integration with the exerting body. I call this intersection 'integrated exertion', and more precisely I define it as the intersection between human–computer integration, where the user and computer co-operate in partnership (Farooq & Grudin, 2017), and exertion support, where the user invests physical effort (Mueller, 2017). This is an emerging area in HCI with potential application across various domains.

To begin exploring this intersection, I formulated the following research question:

How do we design integrated exertion experiences?

In this work I address this question to reduce the gap in knowledge that designing integrated exertion experiences represents. I do so by presenting the results from three case studies that inform a practical and theoretical framework I call the framework for designing integrated exertion, which is targeted at HCI practitioners who wish to support the exerting body from a human–computer integration perspective.

Exertion in human–computer interaction

Exertion is a thriving area of research that spans different domains, such as sports science, health, interactive games, quantified self and more (Bauer et al., 2012; Mueller, et al., 2017; Araki et al., 2018; Khot et al., 2014). Over the years devices and sensors have gotten closer to our bodies to quantify different metrics, such as step count, heart rate, inclination and distance changes (Ketcheson et al., 2015; Tudor-Locke, 2011); this has resulted in users learning about their exertion experience in comparison with their social network (Drake & Cain, 2015; West, 2015). These advances offer HCI practitioners new tools and information to play with when it comes to designing exertion experiences. In turn, these experiences have motivated new theoretical frameworks to understand the combination of the exerting body and the influence of technology on the experience (Brandt, 2006; Mueller et al., 2011; Rozendaal et al., 2011), as well as the distance to other bodies while the user exerts and how the exerting experience can be promoted or hindered (Isbister, 2013; Mueller & Isbister, 2014).

A challenge with the current approaches in many exertion experiences is that often interactive systems are designed with the premise of collecting the user's information to then present insights back to the user, so that the user can think about what the information means in order to make informed decisions. This appears to me as a form of 'cognitive support' as it reveals new information that the user cannot sense with ease, if at all. This form of cognitive support can assist users to reflect on their exertion experience by presenting information; however, it often happens after the exertion experience. This is a missed opportunity since with advances in computing, HCI researchers can begin exploring how to design for the intersection of exertion and human–computer integration to support users during the exertion experience, as I describe in more detail in the next section.

Human–computer integration

In 2016, the term 'human–computer integration' was popularised by Farooq and Grudin on the cover of *Interactions Magazine* (2016). This notion of integration suggested that the interactive system could draw from the user's actions in order to act on the experience with autonomy (Farooq et al., 2017; Farooq & Grudin, 2017) and through this support the user to achieve their goals. Interestingly, the first examples of integration focused on users interacting with screen-based technologies, such as a user completing their tax forms (Farooq & Grudin, 2016). In this case, the system played a supporting role by asking questions about the user to pre-fill information on their behalf, and in other cases prompted the user to make a selection, through this form of integration leveraging the user's and the system's abilities as partners to complete the forms. Beyond screen-based technologies, the next wave of integration focused on automation of processes, assisting users to split tasks between users and systems, such as in a car assembly line with robotic arms (Krüger et al., 2017). This was followed by systems worn on the body, such as exoskeletons that provided the user with extra strength to assist patients or carry cargo in warehouses (Pazzaglia & Molinari, 2016). This shows that technology that is not screen-based can support integration experiences while offering various opportunities for integration with the human body. However, there are various forms of bodily integrations, as I describe next.

Bodily integration

Bodily integration implies that a system is integrated with the human body in order to extend the user's cognitive or physical ability in the context of the experience; this is something I discuss in Chapter 7. To achieve this bodily integration, the human–computer integration vision has focused on systems that can act with autonomy, while previous work has focused on analogue, non-acting human–system integration. I discuss these differences in detail in Chapter 2, and here I provide a summary of the different forms of integration with the human body and the opportunities they offer in relation to my work.

Non-acting bodily integration

Prior work in this area has focused on the phenomenological experience of the user's corporeal awareness being extended, such as a blind person sensing the ground ahead through their walking stick or a bike rider sensing the ground surface through the bike's handle bars (De Preester, 2011; Slatman, 2016). This form of bodily integration suggests that the user's corporeal awareness is extended to include the object at hand (Berlucchi & Aglioti, 1997) and this becomes semi-invisible to the user during the interaction. More recently, researchers have used artificial limbs to study this phenomenon, adding two additional arms controlled by the user using their legs through motion mapping (Sasaki et al.,2017).

This form of bodily integration deals with analogue systems as extensions to the human body that the user controls, and can afford new ways to experience our corporeal awareness during the experience.

Enacting bodily integration

A second form of integration with the human body builds from work exploring systems that can act with autonomy to support and extend the user's physical and cognitive abilities in the context of the experience. This is in line with the vision presented in human–computer integration (Farooq & Grudin, 2016) in that a system aims to work alongside the user as a partner. For example, such systems can increase an eBike's engine support when pollution ahead of the road is high, to support the user physically (Sweeney et al., 2017), or they can deliver an encouraging message while the user is struggling with a challenging run to support a jogger cognitively (Club, 2020).

This form of bodily integration is an emergent area in HCI with vast opportunities for exploration. My work is situated in this area and it focuses on discovering design knowledge to further our understanding of how to analyse and design integration experiences in an exertion context.

Stimulating bodily integration

A third form of integration with the human body builds from prior work that explored integration systems that directly stimulate bodily parts, such as electric muscle stimulation, transcranial stimulation and galvanic vestibular stimulation. Systems in this form of bodily integration also act with autonomy to support the user. For example, researchers have used electric muscle stimulation to actuate the user's hands and fingers (Tamaki et al., 2011), and also the user's hand and forearm (Lopes et al., 2016). Researchers have also used this form of stimulating bodily integration for entertainment purposes, such as using galvanic vestibular stimulation to offer a player the sensation of vertigo and, through this, facilitate new ways to experience our body (Byrne et al., 2016).

This form of bodily integration is a thriving area in HCI with vast opportunities for exploration, however, it is outside of the scope of this thesis.

Integrated exertion

I define the term 'integrated exertion' as the intersection between human–computer integration, where the user and computer co-operate in a partnership (Farooq & Grudin, 2017), and exertion support, where the user invests physical effort (Mueller, 2017). This intersection currently lacks design knowledge in our community; hence with my work I hope to gain a deeper understanding of how to analyse and design these experiences, in order to contribute to the community and enable more integrated exertion experiences that promote the joys and benefits of movement through an integration approach.

My definition of integrated exertion is intentionally broad to encompass many exertion experiences, and builds from the definition of human–computer integration which states that: integration systems can act on to the user’s actions in order to participate in the experience (Farooq et al., 2017; Farooq & Grudin, 2017). My work extends this definition by focusing on an exertion context, including systems that can act on: (1) the user’s movement data, focusing on the user’s actions; (2) the user’s contextual data, focusing around the user’s body; and (3) the user’s physiological data, focusing inside the user’s body. These extensions correspond to each of the integrated exertion prototypes described in Chapters 4, 5 and 6. Through them I was able to study the resulting user experiences that each data type offered to users, in order to collectively map, with the three case studies, the design space the integrated exertion offers (Chapter 7). More narrowly, to explore integrated exertion, I focused on the exertion context of cycling an electric bike, as this allowed the user to exert and electric bikes can be easily modified to explore various forms of integration with the exerting body. I designed the systems to extend the physical and cognitive abilities of the user during the experience when it acts on them. This showed, in the three case studies, that the system can be designed to extend the user’s physical and cognitive abilities during the experience, and that 'how' we design the system to act on them can be seen as a design dimension spanning between causing the user momentarily loss of bodily control and supporting the user in maintenance of bodily control. This points to specific gaps in knowledge in HCI when it comes to designing integrated exertion systems, as the resulting user experiences can vary according to the data used to facilitate the integration between the exerting body and the system.

This thesis begins filling this gap in knowledge by demonstrating how the system acts on the experience through using different data types, and highlights how each of the data types can lead to different user experiences, revealing that the user's agency over the data is correlated in some cases with the user experience, as I describe in Chapter 7. The resulting themes from my case studies can assist HCI practitioners to analyse integrated exertion experiences, while the design tactics offer practical guidance to design future integrated exertion experiences. This is important, as integrated exertion has implications for various areas of research, such as: designing interactive systems, investigating human–system partnerships, designing for health support, studying 'superhuman' sports and designing for emergency team response operations to name a few.

I hope that the presented framework, including the three published case studies can assists to further the general HCI understanding of how to design human–computer integration in an exertion context.

Integrated exertion at the intersection of human-computer integration and exertion

Human-computer integration and exertion can be investigated independently as illustrated in Figure 1 below. For example, there are exertion experiences with interactive systems that do not offer an integration experience, such as where exertion data is collected to inform the user about their athletic performance after the exertion experience (West 2015). In this case, the interactive system works by receiving an input from the user to generate an output. This is interaction.

There are human-computer integration experiences without exertion, such as, when your alarm clock goes off 15 minutes earlier than scheduled due to bad weather so that you have enough time for the commute (Farooq & Grudin 2016). In this case, there is an initiative from the system, similar to that of a partner. This is integration.

At the intersection of human-computer integration and exertion lies integrated exertion, these are experiences where the user is exerting with the system, and the system can sense and interpret data from the experience to take initiative. This is integrated exertion.

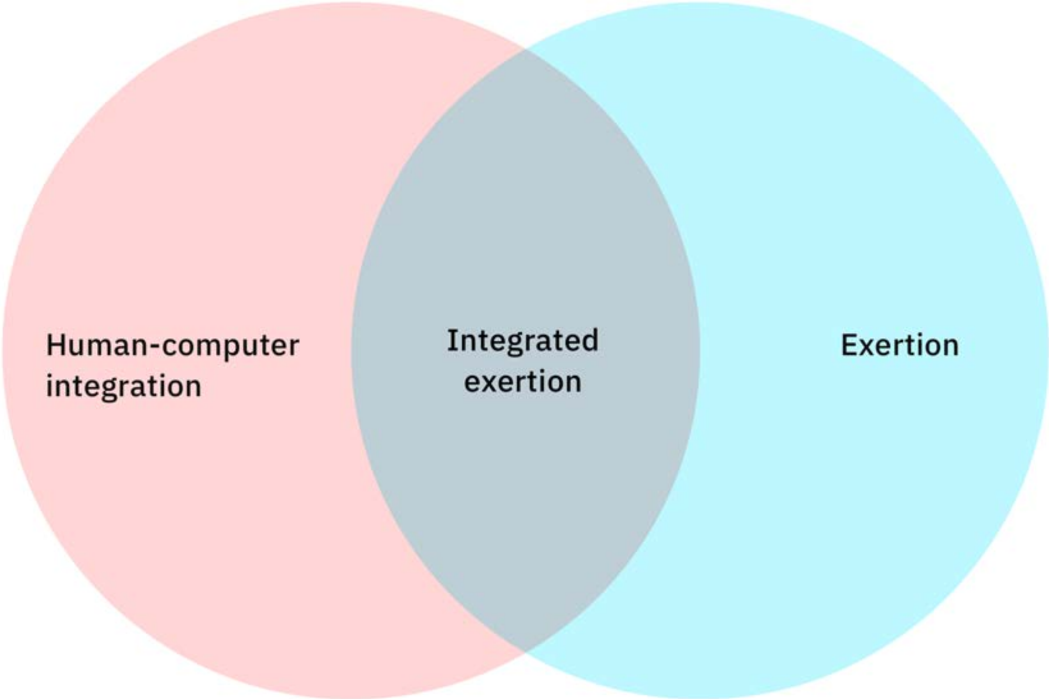


Figure 1. Illustration showing the concepts of human-computer integration and exertion as independent concepts, and their intersection as integrated exertion.

Thesis statement

Through this work I aimed to answer the research question:

How do we design integrated exertion experiences?

To answer this question, I followed an iterative approach by designing and studying three prototypes that each used a different data type to facilitate the integration between the exerting body and the system. This offered the opportunity to study and reflect on three integrated exertion systems. By studying these systems and how users interact with them, I was able to synthesise the collected data into themes and design tactics. Through further consultation with my supervisors and lab colleagues, I iteratively began creating the framework for designing integrated exertion. This framework offers four areas in which HCI practitioners can design integrated exertion system as *partners*, *assistants*, *detractors* and *thrillers*. Each area contains three user experiences; for example, in ‘integrated exertion systems as partners' the user experiences are: co-operative, symbiotic and synchronous, totalling twelve integrated exertion experiences that my work reports on with examples.

In Figure 2 below I present a preview of the framework that HCI practitioners can use to analyse and design integrated exertion experiences; further details can be found in Chapter 7. The framework shows two dimensions. The first dimension is 'The type of support offered to the user' and it spans *designing systems to extend the user’s physical and cognitive abilities* and *designing systems to challenge the user’s physical and cognitive abilities*. The second dimension is 'The degree of control the user has over the system' and it spans *designing systems that act on and cause the user momentary loss of bodily control* and *designing systems that act on and support the user in maintenance of bodily control*.

Framework for designing integrated exertion

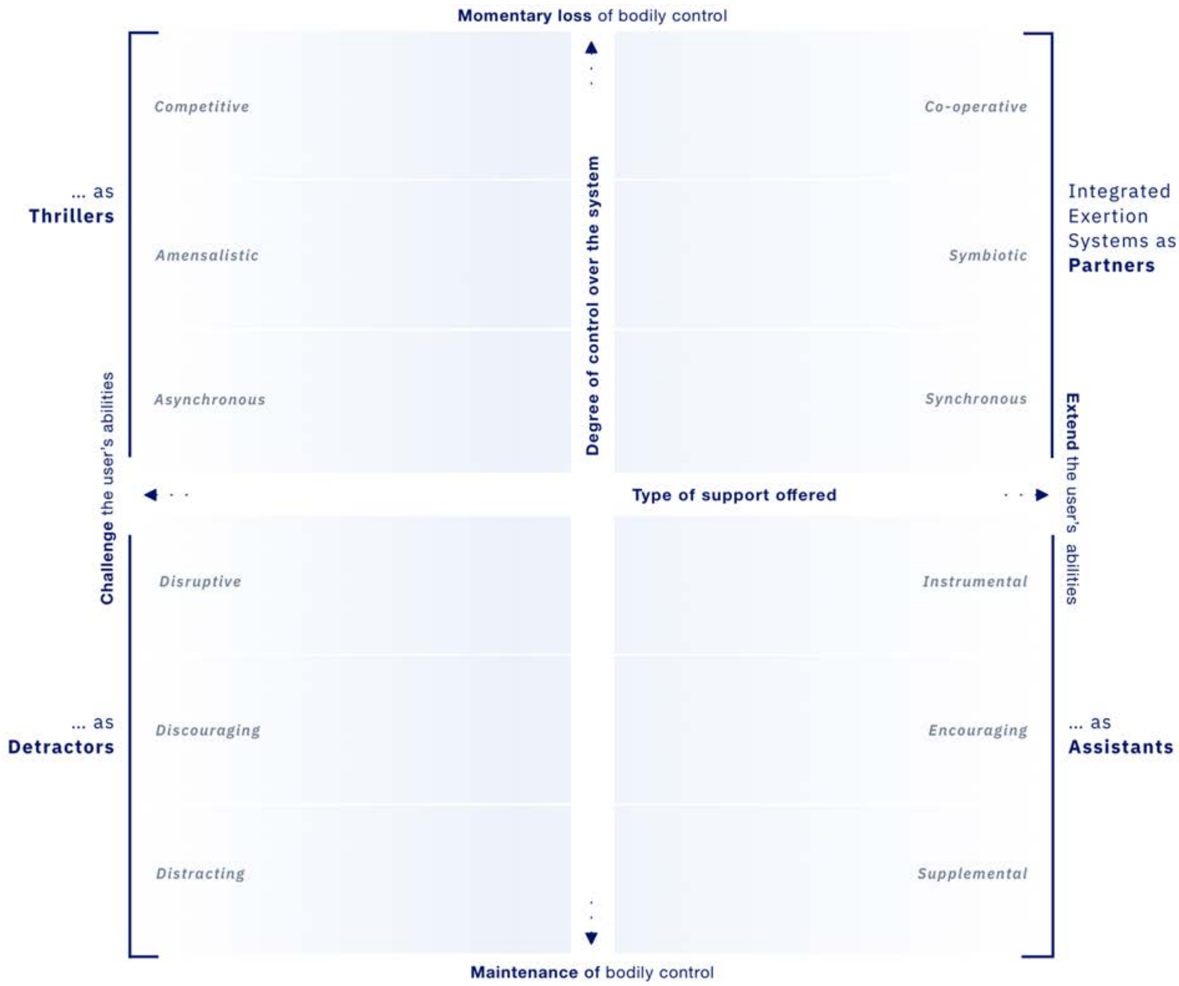


Figure 2. Framework for designing integrated exertion, containing four areas and twelve user experiences.

Research objectives

In order to answer the research question and lead to the development of a theoretical framework for the design of integrated exertion, I aimed to meet the following research objectives:

1. Understand the role of integrated exertion in supporting the exerting body

This objective was achieved through my investigation and discussion of the related work (Chapter 2), where I identified where the exertion and human–computer integration literature meet. This intersection revealed a knowledge gap around how to design integrated exertion experiences, more specifically in relation to supporting the exerting body in the context of the experience by integrating with an interactive system.

2. Explore the applications that integrated exertion offers as a design space

This objective was achieved by exploring each of the prototypes in a different way to integrate with the exerting body, yielding different user experiences that I describe in detail in the framework. In the case study chapters and in the framework I offer practical themes and design tactics to explore integrated exertion as a design space. Moreover, the future work section sets a path for exploration around ways to further integrated exertion and highlights domain-specific applications for integrated exertion systems.

3. Create a theoretical design framework

Through achieving the above objectives, I have been able to create the framework for designing integrated exertion. The framework is based on the three different case studies, exploring different forms of integration in an exertion context. By conceptualising, building and studying the results, I was able to publish each case study at a top-tier conference. This confirmation from the HCI community offered valuable feedback which, alongside my supervisors, I implemented to bring together my theoretical framework for designing integrated exertion experiences.

Research scope

In order to address the research objectives listed above and offer a concrete contribution, I have limited the scope of the thesis to the following aspects:

- As a first exploration into human–computer integration in an exertion context, I have used electric bikes which I modified to create an integrated exertion system. In my work I have not used other electric engine systems such as eSkates, Pedelecs or Exoskeletons, which also allow the user to exert physical effort, supported by an actuator. The reasons for this decision were to limit the number of factors while studying integrated exertion and to gain and carry over design knowledge to explore integrated exertion and make a concrete contribution.

- To study different forms of integrations with the exerting body, I have used three different data types as inputs into the integration system: movement data, collected from the user's bodily movement (Andres et al., 2018); contextual data (traffic light data), collected from around the user's body during the experience (Andres et al., 2019); and physiological data (brain activity via electropherogram), collected from the user's inner bodily processes during the experience (Andres et al., 2020). In my work I have not used other data within these categories or other data types to facilitate integrated exertion experiences. This may be future work.

- All the prototypes were designed for and studied in a street setting in similar environmental conditions to ensure consistency and iteratively carry over design knowledge. I have not studied the prototypes in other environments like mountains, in snow or during nighttime.

- None of the prototypes utilised an intrusive approach to integrate or connect with the exerting body. For example, none of them used implants, bodily modifications or stimulation techniques that directly affect the human body, such as electric muscle stimulation (Knibbe et al. 2018), transcranial magnetic stimulation (Hallett, 2000) and galvanic vestibular stimulation (Byrne et al., 2016).

- This work on integrated exertion does not look to achieve fitness goals, instead focuses on exploring different data types to facilitate the integration between the user and the system.

- The integrated exertion experiences presented in this thesis were designed to facilitate integration in an exertion context within the framework areas of: integrated exertion systems as partners and assistants, as these were the most under-explored. While I present other areas in the framework – integrated exertion systems as detractors and thrillers – in order to understand the design space of integrated exertion, the prototypes created were not focused on either of these areas. This may be future work.

- In my research, I have focused on exploring the design space of integrated exertion from a qualitative perspective. Through this exploration, I derived three novel integration approaches that open up a future research agenda that could study, for example, quantitatively how the presented approaches measure against current eBike interaction mechanisms. Such a quantitative approach is not in the scope of the present thesis and can be part of future work.

Case studies

In this section I present three case studies designed towards exploring my research question. Each system informed the design of the next and they also used different types of data to integrate with the exerting body. As such, I begin by listing the categories of data and the corresponding data types that I explored (Table 1).

Table 1: The data categories on the left, and data types used in the Case Studies on the right.

Case Study	**Data Category**	**Data Used**
1	Movement	Bodily inclination
2	Contextual	Traffic light and speed
3	Physiological	Electroencephalogram (EEG) for neurological activity

Case Study 1: Movement data

I began by exploring integrated exertion systems that act on the user's **movement data**, in the exertion context of cycling, in order for the system to act on the experience and extend the user's physical abilities.

I used the user's leaning forward position to embrace speed while cycling as a 'movement' that the system acted on by increasing engine support synchronously as the user leaned forward. The second body movement I used was when the user was standing up to resume riding; this turned on the eBike's hazard lights automatically to support the rider, as eBikes can become wobbly because they are heavier than regular bikes.

The rider's body movements were monitored using a mobile phone's gyroscope attached around the rider's chest, as described in Chapter 4. The inclination coordinates served as inputs to the integrated exertion system.

Selected experience quotes from Ava the eBike (Chapter 4):

is like the power comes from my body when I lean, and not from the engine, it makes me feel stronger

I felt it was a pleasant and simple way to accelerate

I like that the power is always there for you, I liked to use the body acceleration and take the curves exaggeratedly as if I was motorbike racing.

Case Study 1: profile

Table 2: Case Study 1 profile.

Chapter 4	Ava the eBike - 'I had superpowers when eBike riding': Towards understanding the design of integrated exertion 
Publications	Andres, J., De Hoog, J., von Känel, J., Berk, J., Le, B., Wang, X., ... & Mueller, F. (2016, October). Exploring Human: EBike Interaction to Support Rider Autonomy. In *Proceedings of the 2016 Annual Symposium on Computer–Human Interaction in Play Companion Extended Abstracts* (pp. 85–92). ACM. https://doi.org/10.1145/2968120.2987719 Andres, J., de Hoog, J., & Mueller, F. (2018, October). I had super-powers when eBike riding Towards Understanding the Design of Integrated Exertion. In *Proceedings of the 2018 Annual Symposium on Computer–Human Interaction in Play* (pp. 19–31). ACM. 10.1145/3242671.3242688
Ethics approval	CHEAN A 0000020291-07/16
Description	The intersection of the physically active human body and technology to support it is in the limelight in HCI. Prior work mostly supports exertion by offering sensed digital information about the exertion activity. I focus on supporting exertion during the activity through sensing and actuation, facilitating the exerting body and the bike to act on to each other in what I called 'integrated exertion'. I draw on my experiences of designing and studying Ava the eBike, an augmented eBike that draws from the exerting user's bodily posture to regulate engine support.
Research question	How do we design integrated exertion systems that can act on the user's movement data to support the user experience?

Data collection	Ava was deployed to participants' houses (22 bike riders) for two weeks. I asked participants to collect images, notes and content that could assist them in telling me about their experience. I used semi-structured interviews after the two weeks (Blandford, 2013).
Analysis	Thematic analysis was used for analysis of the data (Braun & Clarke, 2006).
Themes	Interacting with Ava [Cycling Ava was engaging. Ava supported natural interaction]. Experiencing Ava [Ava was more experiential than participants' eBikes. Ava facilitated make-believe. Cycling Ava felt like performing]. Reduced body control over Ava [Experiencing reduced body control over Ava]. Ava's technology [Suggestions for improvement. Hazard lights were not mentioned often].
Design tactics	Support rider autonomy by allowing the rider to choose when and how much assistance to access. Promote more natural interaction with the system, higher physical engagement and a higher sensory experience for the user with ongoing actions. Design for zero body disparity to facilitate the rider to be one with the system. Fine-tune the assistance response to be gradual yet strong to offer a more enjoyable experience. Consider amplifying any sensation by engaging other senses to facilitate make-believe. Offer momentarily reduced body control without the user's goals in mind (thrill and discomfort). Offer momentarily reduced body control with the user's goals in mind (a sense of working together).

Case Study 2: Contextual data

The learnings from the first case study led me to consider how the system acts on in the experience and, instead of acting on the rider leaning to increase engine support, I asked whether the system could act by using contextual data, such as information from the user's environment, in order to act on the experience and extend the user's physical and cognitive abilities.

In the second case study I explored systems that can act on the user’s **contextual data** by using traffic light data and a speedometer to measure the rider’s speed. Based on this data I designed the system to act by increasing engine support, causing the rider to momentarily lose bodily control over the system in order to extend the physical ability of the rider to go faster to catch the next traffic light on green. Secondly, the system can also act by whispering in the rider’s ears to 'slow down a little'. This supports the rider to maintain bodily control over the system while receiving instrumental information that extends their cognitive ability, to know when to slow down to match their speed with the traffic light patterns to catch the next traffic light on green.

Selected experience quotes from Ari the eBike (Chapter 5):

It felt like a guided bike riding, like the bike was my teacher almost

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’

A horse, you ride it like a bike and it can sense things that humans can't. Similarly bats or dolphins with echolocation.

Case Study 2 profile

Table 3: Case Study 2 profile.

Chapter 5	Ari, the eBike – 'Co-riding with my eBike to get green lights': Towards understanding the design of integrated exertion 

Publications	Andres, J., Kari, T., von Kaenel, J., & Mueller, F. F. (2019, June). Co-riding With My eBike to Get Green Lights. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (pp. 1251–1263). ACM. https://doi.org/10.1145/3322276.3322307
Ethics approval	CHEAN A 21422-05/18
Description	Researchers are increasingly exploring interactive technology supporting human–system partnership in an exertion context, such as cycling. So far, most investigations have supported the rider cognitively, by the system 'sensing and presenting' information to assist the rider to make informed decisions. In contrast, I propose systems that promote user–system co-operation, by 'sensing and acting' on information to assist the rider, not only cognitively but also physically, with the aim of facilitating user–system co-operation in an exertion context. My prototype Ari is a novel augmented eBike designed to facilitate user–system co-operation, where the information that each party can sense is used in regulating the speed to cross all traffic lights on green.
Research question	How do we design integrated exertion systems that can act on contextual data to support the user experience?
Data collection	I invited 20 bike riders individually to a location to test Ari, lasting approximately an hour and a half each session. Using the explicitation approach (Vermersch, 1994), I asked questions during the session to capture qualitative information.
Analysis	Thematic analysis was used for analysis of the data (Braun & Clarke, 2006).
Themes	Meeting the system [Participants' curiosity about how the system works. Expectations of Ari]. Learning to co-operate with the system [When the system acted. Users' experience of sound. Building trust with the system. Co-operating with the system]. Social aspects of cycling [Riders adjusted their cycling efforts to benefit from Ari. Riders can be envious but also proud of co-operative cycling]. Reminiscing moments. Participants' suggestions.

Design tactics	Contextual cues to facilitate skill integration Contextual meaning to craft system response Drawing from human–animal co-operation to inform human–system co-operation Making co-operative systems more trustworthy Making co-operative systems inclusive Adjusting the user's perception of control over the co-operative system

Case Study 3: Physiological data

Having explored integrated exertion systems that act on the user's movement and contextual data, I next explored yet another integration mechanism by using physiological data pertaining to internal bodily processes of the user. This step seemed logical to me and the team, as the sports science community had investigated the mapping between a user's changes in the field of view relating to peripheral awareness via electroencephalogram (EEG) (e.g. (Lemmink et al., 2005; Nan et al., 2014; Nan et al., 2013)). This meant that changes to peripheral vision which facilitate higher awareness of the environment for improved physical performance, such as cycling and navigating the environment, could potentially be detected in real time to offer or stop offering engine support to the user when cycling. Through the implementation described in Chapter 6 (Ena), I achieved this integration with the exerting body and learned that my system can gain access to a user's pre-attentive processing state. This means that the system can stop engine support by acting on changes in the user's field of view read from their brain in real time, facilitating a form of extended physical and cognitive ability to navigate the environment while cycling.

Selected experience quotes from Ena (Chapter 6):

It was coming from my brain wave, but the system could slow down before I could act on to 'hit the brakes', it was uncanny but useful

It felt like the bike was drawing upon my perception of how safe the way ahead was

the bike is trying to ensure that I'm in sync with myself and my own thoughts, using my signals.

Case Study 3 profile

Table 4: Case Study 3 profile.

Chapter 6	Ena the eBike – 'Using peripheral awareness as a neurological state for integrated exertion': Towards understanding the design of integrated exertion 
Publications	Andres, J., Schraefel, M., Semertzidis, N., Dwivedi, B., Kulwe, Y., von Kaenel, J., & Mueller, F. (2020, April). Introducing Peripheral Awareness as a Neurological State for Human–Computer Integration. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM. https://doi.org/10.1145/3313831.3376128
Ethics approval	CHEAN A&B 22071-03&04/19
Description	I introduce peripheral awareness as a neurological state for integrated exertion, where the user is assisted by a computer to interact with the world. Changes to the field of view in peripheral awareness have been linked with quality of human performance. This instinctive narrowing of vision that occurs as a threat is perceived has implications in activities that benefit from the user having a wide field of view, such as cycling to navigate the environment. I present Ena, a novel EEG–eBike system that draws from the user's neural activity to determine when the user is in a state of peripheral awareness to regulate engine support.
Research question	How do we design integrated exertion systems that can act on the user's physiological data to support the user experience?
Data collection	I invited 20 bike riders individually to a location to test Ena, lasting approximately an hour and a half each session. Using the explicitation approach (Vermersch, 1994), I asked questions during the session to capture qualitative information.
Analysis	Thematic analysis was used for analysis of the data (Braun & Clarke, 2006).

Themes	Participants' user experience highlights [The system is integrated with my brain and it can act on before I do. The world became a video game. The experience can be elating, dramatic and surreal] The user experience of peripheral awareness as a mechanism for integration [The system responded to how I was seeing the world. Strategies for reaching peripheral awareness. In sync control between the rider and the system. Reflections on controlling the system's engine support using peripheral awareness] Internal bodily signals observed by users [I had to be in sync with myself before I could be in sync with the system. It is a relaxed state, not a focus state]. Human–system symbiotic relationship [Using information directly from the user's brain was scary for some users and also interesting. The system kept me safe]. Explicability and trust to support human–computer interaction [The system was intuitive for most users. I trusted the system once I realised it was helping me to be safe. Participants describe in their own words what the system does]. Participant suggestions [Participants made suggestion to combine inside of the body data with computer functions. Participants wished initially for more feedback via other sensory channels].
Design tactics	Use peripheral awareness as a neurological state to study human performance during interactions. Use peripheral awareness as a neurological state for integration experiences. Use peripheral awareness integration with kinetic feedback to facilitate users to develop connectedness with their body and the system. Use peripheral awareness integration to offer users opportunities for mastery. Use peripheral awareness integration in real time to create symbiotic-like experiences. Use peripheral awareness integration to promote users trust in the system.

Contributions

My work makes the following contributions:

1. This thesis contributes design knowledge by providing details gained from conceptualising, designing and studying three different integrated exertion systems.

2. The case studies demonstrate different data types as means of creating an integration between the exerting body and the system, reporting on the resulting user experiences and offering themes to analyse and design tactics to create various integrated exertion experiences.

3. This research presents the framework for designing integrated exertion experiences. This framework is the first theoretical conceptualisation of how to design integrated exertion experiences. In the framework, I bring together each of the case studies and expand on what this design space can offer to HCI practitioners by detailing twelve different user experiences, six dimensions and offering reflections for future work.

Peer reviewed publications

Table 5: Peer reviewed publications list.

Integrated exertion case studies

Andres, J., Schraefel, M., Semertzidis, N., Dwivedi, B., Kulwe, Y., von Kaenel, J., & Mueller, F. (2020). **Introducing Peripheral Awareness as a Neurological State for Human–computer Integration.** *In Proceedings of the SIGCHI conference on Human Factors in computing systems.*
doi.org/10.1145/3313831.3376128

Andres, J., Kari, T., Kaenel, J. v., & Mueller, F. (2019). ***"Co-riding With My eBike to Get Green Lights".*** In Proceedings of the 2019 on Designing Interactive Systems Conference, San Diego, CA, USA.
doi.org/10.1145/3322276.3322307

Andres, J., de Hoog, J., & Mueller, F. F. (2018). **"I had super-powers when eBike riding" Towards Understanding the Design of Integrated Exertion.** *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play*.
10.1145/3242671.3242688

Andres, J., De Hoog, J., von Känel, J., Berk, J., Le, B., Wang, X., Brazil, M., & Mueller, F. (2016, October). **Exploring Human: EBike Interaction to Support Rider Autonomy**. In Proceedings of the 2016 Annual Symposium on Computer–Human Interaction in Play Companion Extended Abstracts (pp. 85–92). ACM.
doi.org/10.1145/2968120.2987719

Collaborations on body-centric computing that contributed to furthering my work

Mueller, F., Kari, T., Li, Z., Wang, Y., Mehta, Y., **Andres, J**., Marquez, J., & Patibanda, R. 2020. **Towards Designing Bodily Integrated Play**. In Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20). Association for Computing Machinery, New York, NY, USA, 207–218.
doi.org/10.1145/3374920.3374931

Andres, J., Schraefel, M. C.., Patibanda, R., & Mueller, F, F. 2020. **Future InBodied: A Framework for Inbodied Interaction Design**. In Extended Abstracts of the 2020 TEI Conference on Tangible, Embedded, and Embodied Interaction (TEI '20). doi.org/ 10.1145/3374920.3374969

Andres, J., Schraefel, M. C.., Tabor, T,. & Eric B. Hekler. 2019. **The Body as Starting Point: Applying Inside Body Knowledge for Inbodied Design.** In Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19). Association for Computing Machinery, New York, NY, USA, Paper W32, 1–8. doi.org/ 10.1145/3290607.3299023

Schraefel, M. C.., van den Hoven, E,. & **Andres, J**. 2018. **The Body as Starting Point: Exploring Inside and Around Body Boundaries for Body-Centric Computing Design.** In Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA '18). Association for Computing Machinery, New York, NY, USA, Paper W02, 1–7. doi.org/10.1145/3170427.3170638

Schraefel, M. C.., Bateman, S., Friday, A., & **Andres, J.** 2019. **The uncomfortable workshop: exploring discomfort design for wellbeing and sustainability.** In Adjunct Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2019 ACM International Symposium on Wearable Computers (UbiComp/ISWC '19 Adjunct). Association for Computing Machinery, New York, NY, USA, 1083–1086.
doi.org/10.1145/3341162.3347767

Mueller, F. F., **Andres**, **J**., Marshall, J., Svanæs, D., Gerling, K., Tholander, J., ... & Höök, K. (2018). **Body-centric computing: results from a weeklong Dagstuhl seminar in a German castle.** Interactions, 25(4), 34–39.
https://bit.ly/2QVSJ68

Thesis structure

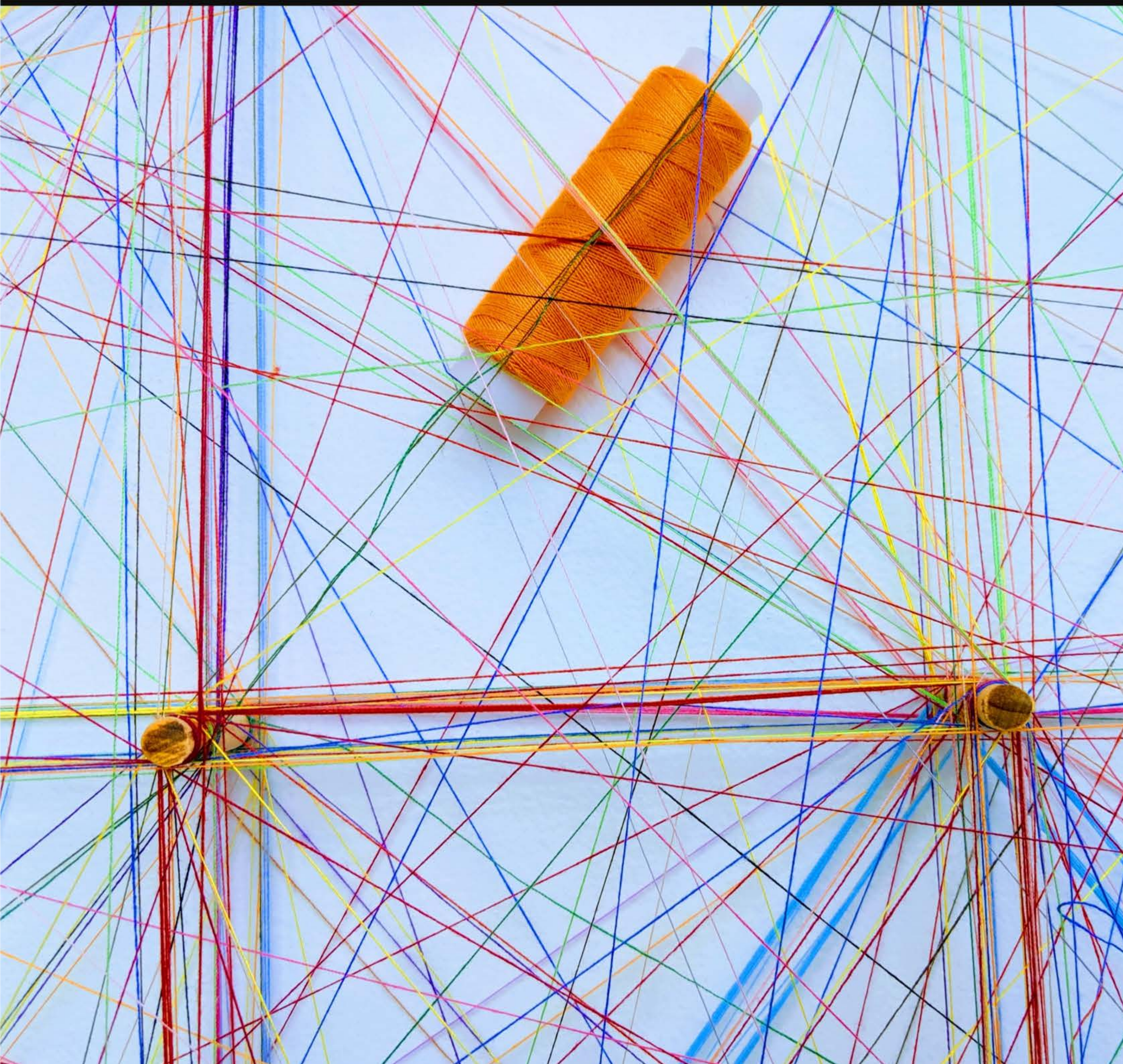
Table 6: Thesis structure.

Chapter 1	Introduction: An overview of the research, motivation and thesis statement
Chapter 2	Background and related work on integrated exertion
Chapter 3	Description of the methods followed for conducting the research
Chapters 4, 5 and 6	Details of the development and evaluation of three case studies to explore the research question
Chapter 7	Introduction to the framework for designing integrated exertion experiences
Chapter 8	Conclusion and future work

CHAPTER 2

Related work

Positioning integrated exertion.



CHAPTER 2 – Related Work

This thesis focuses on understanding the design of integrated exertion; therefore, I start by describing prior work on exertion and human–computer integration theory to highlight the design space at this intersection. I describe the different forms of bodily integration and where my work is situated. I also present related work on cycling in HCI, eBike riders and the opportunities around supporting the exerting body cycling with technology. Finally, this chapter concludes by presenting the research opportunities that integrated exertion offers.

The evolution of exertion experiences in HCI

I start with a timeline of how technology has supported the exerting body in HCI; exertion experiences are defined as: systems where the user is investing physical effort as part of an exertion experience (Mueller et al., 2011).

*From **playing** with digital systems, to **using our bodies** to interact with digital systems, to **integrating our bodies** with digital systems.* (Mueller et al., 2017)

Figure 3. The evolution of exertion experiences in HCI.

From playing with digital systems

Early interactive systems that began exploring how to support the exerting body moved from controllers and joysticks to interactive mats, where the user could stretch, dance, jump and run by stepping on defined targets on the mat as inputs into the system (Andrews, 2007; Bogost, 2005). This approach offered users the opportunity to follow a series of movements to operate the system by pressing the inputs on the mat as a means of using their bodies to interact with digital content.

Using our bodies to interact with digital systems

The next system that furthered this vision focused on using image recognition of the user's body as input to control digital content or using controllers with motion-tracking sensors to detect the user's movements in order to control digital content (Isbister, 2013). This approach provided users with more mobility options, as the user's input into the system was not based on pressing defined targets as buttons. This meant the designers of such experiences could design for any particular movement (e.g. punching, standing on one leg or swinging a racket), rather than having to use button presses as the only means of input.

The limitation with this approach remained in that the exerting body was constrained to a fixed location to interact with the digital content, mostly because the mechanism to input commands into the system was limited to the range of view of the tracking device and motion sensors. This notion of using the body as an input challenged the approach of sitting to interact with technology and invited users to exert while using the technology, in what was dubbed 'exertion games', which are games that require and encourage physical exertion while interacting with interactive systems (Mueller et al., 2014). These experiences with technology inspired others to study the phenomenological experience of the moving body and our interactions with technology, from somaesthetic design to the space that such interactions offer for social and playful interactions (Höök et al., 2015; Márquez Segura et al., 2013). This type of exertion experience provides users with new ways to experience and enjoy interacting with technology.

Integrating our bodies with digital systems

To take a step forward in how we as HCI practitioners can support the exerting body through technology, in recent years advances in computing have facilitated the design of systems that are portable, work wirelessly and can process vast amounts of information on the go e.g. ((Dasgupta et al., 2008; Schirner et al., 2013; Swan, 2012)). This facilitates the creation of interactive systems that can sense and interpret data and act on the experience alongside the user. This opens new forms of interaction with users beyond screen-based technologies to facilitate integration between the user and the system that unfolds in the physical world (Al-Hrathi et al., 2012; Bekker et al., 2010; Kunze et al., 2017; Leigh et al., 2017; Rekimoto, 2019). As such, exertion experiences in HCI have begun a journey to explore integrating our bodies with digital systems to discover new ways in which technology can support the user experience.

To deepen my understanding of exertion experiences and how to integrate the exerting body with interactive systems, I lean on previous work to build on their knowledge; for example, The 'exertion framework' (Mueller et al., 2011) investigates digital technology to design and extend exertion games through four lenses: the responding body, the moving body, the sensing body and the relating body. Each lens moves away from the body and suggests considerations when designing for the exerting body. Interestingly, from this framework I learned about the role of technology to support the exertion experience and what happens as technology moves closer to our bodies. Moreover, these lenses were created when interactive systems did not yet have the ability to act on information and required user input to generate an output. With this in mind, my framework offers an extension to this framework by studying integration systems in an exertion context, offering a refresher on the role of technology to support exertion experiences. More precisely, I offer insights from studying three different integration mechanisms with the exerting body based on the user's movement data, their contextual data and their physiological data. This results in design knowledge to design superpower-like experiences, facilitate user–system co-operation and human–system symbiotic integration and, through this, contribute to furthering our understanding of how to support the exerting body through an integration approach.

My work also takes inspiration from prior work that focuses on users interacting in the physical world without screens, for example 'embodied interaction' (Dourish, 2004) and 'designing with the lived body' (Svanæs, 2013), which take a phenomenological approach to tangible experiences and designing for and with the body. My framework also makes a contribution to this line of work by facilitating users to experience the exerting body in new ways, such as having extended physical strength or cognitive ability to learn about data around their body which they can act on to their benefit during the experience. This offers users a broader range of experiences while integrating their bodies with technology during exertion.

Other works that also inform user interactions in the physical world which have inspired my work are those of (Ishii et al., 2012; Ishii & Ullmer, 1997). This work focuses on the tactile qualities of interacting with objects, limiting or removing the use of screens to facilitate interactions that unfold in the physical world. This is a philosophy I have followed through my case studies to enable users to focus on the experience of cycling and experience the exerting body. More generally, my work was informed by frameworks focusing on the moving body, such as those of Laban (2011) for dance, freedom of movement and self-expression, and Tholander (2010) for sports movement and performance. From these frameworks, I carefully designed my prototypes, considering how users interact with the integration system, with the goal of inviting users to ride in their own way, to facilitate exploration and self-expression and allow users to find a way to integrate with the system.

HCI practitioners can learn from these frameworks to gain an understanding of how the HCI community has placed the human body at the centre of the experience. In the next section I explore the rise of human–computer integration and its enablement of integrated exertion experiences.

Human-computer integration

Farooq and Grudin took a stance beyond HCI to state that human–computer integration 'implies partnership [where] partners construct meaning around each other's activities, in contrast to simply taking orders' (Farooq et al., 2017; Farooq & Grudin, 2017). In Chapter 1 I described how initial exploration around human–computer integration had focused on screen-based technologies to assist users to more effectively complete tasks. Researchers continued this line of work by exploring human–computer integration with the exerting body in 'superhuman sports' (Kunze et al., 2017), from which intriguing user experiences can be facilitated through sports activities referring to the Paralympics and also novel exertion games (Araki et al., 2018). I argue that integration presents opportunities for designing integrated exertion as the user and the system work together in a partnership towards an engaging exertion experience. This has led me to consider how an interactive system can construct meaning from the exerting body during the experience.

The era of human–computer interaction is giving way to the era of human–computer integration—integration in the broad sense of a partnership or symbiotic relationship in which humans and software act with autonomy, giving rise to patterns of behavior that must be considered holistically
(Farooq & Grudin, 2017).

Cyber-physical systems

I also take inspiration from cyber-physical systems, which are systems designed to respond to external data to actuate or change their state (Baheti & Gill, 2011; Schirner et al., 2013). Most of the efforts around cyber-physical systems have focused on manufacturing and industrial applications, exploring how a system can communicate with another system in order to automate a process (Liu et al., 2017; Lu et al., 2015). Interestingly, there are now efforts to include a human 'in the loop' with the cyber-physical systems (Schirner et al., 2013). So far, however, this has been studied from an architectural and engineering perspective to demonstrate working prototypes which often do not focus on the user experience. As such, there is limited design knowledge around the user experience in this area that closely relates to human–computer integration to design for a human-in-the-loop cyber-physical system experience. Therefore, my work taps into this opportunity to contribute design knowledge around how to analyse and design human–system integration experiences with an emphasis on exertion.

Bodily integration

Bodily integration focuses on a human integrating their body with a system. Importantly, I make a distinction between three forms of bodily integration informed by this literature review, my framework and each of the case studies. The first form of bodily integration is 'non-acting bodily integration'; this focuses on systems outside of the human–computer integration vision because these systems do not act with autonomy, but rather serve as extensions of our body that are user-controlled. The next two forms of bodily integration are 'enacting bodily integration' and 'stimulating bodily integration', which extend the vision of human–computer integration, as these systems do act with autonomy alongside the user, while they differ in how they integrate with the human body.

Non-acting bodily integration

Before the technology advances that facilitate human–computer integration became available, previous work had focused on a large area of HCI around the human body and our interactions with objects and technology. This drew from embodied interaction (Dourish, 2004), movement-based interaction(Mueller & Isbister, 2014), exertion interfaces (Mueller et al., 2011), somaesthetic design (Höök et al., 2016) and body-centric computing (Andres, et al., 2020; Churchill, 2015; Mueller et al., 2018) in order to study the human experience when interacting with objects and technology. These efforts in turn inspired the creation of various frameworks that informed my work. For example, Hornecker and Buur (2006) described the relationship between human bodies and tangible objects, highlighting the potential of objects to change their shape in response to human movement. Loke et al. (2013) emphasised the relationship between the moving body and the audience as controllers of an interactive environment. Larssen et al. (2004) studied exertion games in order to understand movement as input for interaction. Their work explored the relationships of the moving body while interacting with objects, systems and people.

I now turn to the experience that humans can have when interacting with objects that are attached to their body as a form of bodily integration. For example, the Youbionic (Koprnický et al., 2017) integrates with the human body as an additional hand to enable the user to grab objects. Metalimbs (Sasaki et al., 2017) integrate with the human body as additional arms controlled by the user with their feet. These extra limbs, attached to the user’s body and controlled by the user, offer from a neurology perspective important details around how our brain includes the system as if it were part of our body. This is based on the mental construct of the body in the brain, or body schema for short, made from visual, tactile and proprioceptive information relating to our corporeal awareness which can be extended to include objects that have a systematic relation to the body, for example a tennis player's racket, a bike rider's bike and tools such as a hammer (Berlucchi & Aglioti, 1997; Maravita & Iriki, 2004). These inclusions into our body schema are often temporary in relation to the situation; when the tennis player stops playing and releases the racket, the racket is no longer part of the body schema and the player does not experience a sense of loss or ownership over the racket as if it was a part of their body (Maravita & Iriki, 2004).

More recent work relating to bodily integration with analogue systems has focused on advancing our understanding of using prostheses, as these are attached to the body for extended periods of time. In this area of prostheses, (De Preester, 2011) suggests that three types of prostheses exist: (1) prostheses that complement our motor ability, such as using a prostheses to replace a lost limb; (2) prostheses that complement our sensorial ability, such as a blind person using a walking stick to sense the ground ahead; and (3) prostheses that complement our cognitive ability, such as a person with a hearing deficiency using a hearing aid. Interestingly, the division between prostheses one and two is interdependent, as a replacement limb can support motor movement and also support our sensorial ability.

I learned from these studies that bodily integration with analogue objects, technologies and prostheses has been explored thoroughly from various perspectives and that it offered a foundation to my work. What was missing and my work can contribute to is our understanding of bodily integration with technology that can act on the experience with autonomy, two forms of which I describe next.

Enacting bodily integration

This type of bodily integration takes a human–computer integration approach in that systems can act with autonomy alongside the user to support the user experience. This is because the underlying programmable software in the integration system uses algorithms to interpret data in relation to the user experience (Farooq et al., 2017); the output from this interpretation serves as an input into the integration system to facilitate the system to act on the experience without requiring user input. This means that data in a human–computer integration approach is fundamental to facilitate the experience of 'integration'. As such, I use different data types and provide examples to describe various forms of integration with the human body, more precisely by focusing on the exerting body to discuss integrated exertion.

Integration systems that act on the user's movement data

These are integration systems that use the user's movement data to act on the experience. For example, an integrated ice-skating dress was designed (Häkkilä et al, 2018) which acts on the dancer's pirouettes to create an aesthetic expression such that when the dancer moves, the state of LEDs embedded in the dress changes.

There are limited examples of this type of bodily integration focusing on using movement data, which suggests to me that there are opportunities for exploration to understand how to design for this type of experience.

Integration systems that act on the user's contextual data

These are integration systems that use contextual data from around the user's body to act on and support the user experience. For example, De La Iglesia et al. (De La Iglesia et al., 2018) created a cycling system that responds to the route's slopes, increasing the pedalling difficulty to incrementally challenge the rider towards improving physical activity. Sweeney et al. (Sweeney et al., 2017) monitored pollution levels ahead of the road so that their eBike could increase engine support and assist the rider with reducing their breathing rate to avoid breathing too much polluted air.

These works show that integration systems can act on the user's contextual data to support and create new user experiences. However, these examples focused primarily on the implementation and modelling perspectives, and offer limited guidance around how to design for and study the user experience that these types of systems can offer.

Integration systems that act on the user's physiological data

These are integration systems that use physiological data from inside the user's body to act on and support the user experience. For example, the heart rate eBike (Motors, 2014) uses the user's heart rate to regulate the eBike's engine support, resulting in more support when the user's heart rate is above average. The e-Sweat Bike Assist (Murugesan et al., 2017) focuses on preventing the rider from perspiring by monitoring physiological signals e.g. if the rider exceeds the sweat threshold, the engine support increases.

These works show that integration systems can act on the user's physiological data to support and create new user experiences. These also focused on the feasibility of implementation and offer limited guidance around how to design for and study the user experience that these types of systems can offer.

In summary, works on enacting bodily integration have focused on the user's body with movement data, around the user's body with contextual data and inside the user's body with physiological data. While a few prototypes exist, these have not focused on the user experience in order to inform future work on enacting bodily integration. This offers a specific gap in knowledge that I seek to begin addressing with my work.

Stimulating bodily integration

In this form of bodily integration, systems also act with autonomy to support the user experience. The difference is that these systems directly stimulate body parts, such as using electric muscle stimulation, transcranial stimulation or galvanic vestibular stimulation to support the user experience. As in the previous form of bodily integration, data is fundamental to the experience of integration; therefore, I also used different data types to make sense of related work in this form of bodily integration. My work does not focus on this specific form of bodily integration as it does not stimulate bodily parts.

Systems that act on the user's movement data

An example of an integration system that uses movement data to act on the experience by stimulating body parts is Balance Ninja (Byrne et al., 2016), a balancing game that uses galvanic vestibular stimulation to deliver an electrical current to the user to make the act of balancing challenging. The electrical current is triggered by the user's movement, resulting in an entertaining experience.

There are limited examples of this type of bodily integration focusing on using movement data to directly stimulate body parts.

Systems that act on the user's contextual data

An example of an integration system that uses contextual data to act on the experience to support the user by stimulating body parts is PossesedHand (Tamaki, 2011) which stimulates the users joints in the hand to control hand and finger movement to support the user with for example practicing and learning how to play a music instrument. Another example is Affordance++ (Lopes et al., 2015), where the system uses electric muscle stimulation to actuate the user's arm muscles in order to communicate an interaction with an object, such as shaking when picking up a spray can.

This form of bodily integration that stimulates body parts offers various works to understand and design for the user experience. However, it only focuses on systems that stimulate body parts, often via electrical muscle stimulation.

Systems that act on the user's physiological data

An example of an integration system that uses physiological data to act on the experience to support the user by stimulating body parts is FootStriker (Hassan et al., 2017). This is a wearable running electrical muscle-stimulation system that detects heel striking via electromyography to detect activity produced by skeletal muscles and actuates the calf muscles during the flight phase to control the foot angle before landing, with the goal of improving running technique.

There are, however, limited examples of this type of bodily integration focusing on using physiological data to directly stimulate body parts.

In summary, works on stimulating bodily integration have focused on the user's body with movement data, around the user's body with contextual data and inside the user's body with physiological data to directly stimulate body parts.

Transhumanism and cyborgs

Another area of research I take inspiration from is the vibrant movement of transhumanism (Alcaraz, 2019; Guler et al., 2016; Haraway, 1990; Harbisson & Ribas, 2019; Wendykowska, 2014), which focuses on integrating our bodies with technology by using implants and performing bodily modifications in order to extend or complement sensorial qualities. For example, Moon Ribas has haptic implants that offer haptic feedback according to seismic activity from around the world, enabling her to experience our planet's 'heart beat' in her body (Chan, 2017). Neil Harbisson has an antenna with a camera implanted in his skull. This camera allows him to experience invisible parts of the electromagnetic spectrum such as infrared and ultraviolet, as well as colour perceptually unavailable to the human eye, by way of transforming light frequencies into musical notes, enabling him to experience colour as sound (Alfaro et al., 2015). In the medical domain, brain implants have been used in the bionic eye (Ong & da Cruz, 2012) to modulate neurons in order to offer users neural activation corresponding to interpreting light frequency as sight. Another example is brain implants to assist epilepsy patients by modulating neural activity via the vagus nerve in order to reduce epileptic activity (Uthman et al., 2004).

These examples show that technology can extend the user's abilities whether for perception extension (Schmidt, 2017a), where the user can experience information beyond their 'standard' sensing abilities to have another reality reveal itself, or to complement sensorial operations in order to live a better life. While this movement and medical practices are gaining momentum in the mainstream, there is still only limited knowledge that reports on the user experience of this form of bodily integration. Additionally, most of the efforts here have not focused on an exertion context without the need for intrusive surgery. As such, my work can serve as a complementary perspective in order to deepen our understanding of extending a user's abilities without the need for intrusive surgery. From this transhumanism perspective I learnt about the ethical considerations when integrating our bodies with technology, something I reflect upon in Chapters 7 and 8.

Why eBikes as a research vehicle?

eBikes (short for electric bicycles) are popular worldwide, most likely because they make cycling accessible for more people as a result of the electrical assistance which allows riders to go further and faster than with regular bikes (Fishman & Cherry, 2016; Plazier et al., 2017). With over 40 million sold in 2016 (Fishman & Cherry, 2016; Salmeron-Manzano & Manzano-Agugliaro, 2018), eBikes allow more people to reap the benefits of engaging in physical activity and the joys of cycling with others, especially in an outdoor setting, while supporting environmentally conscious choices (Plazier et al., 2017). Besides their popularity, there is extensive and established literature that talks about eBike cycling challenges worldwide (e.g. (Johnson et al., 2011; Brezina & Hildebrandt, 2016; Petzoldt et al., 2017; Yang et al., 2018)). In my work, I used some of these challenges as a foundation to envision how I might use an integration approach to begin imagining and exploring futures that can improve the current state. For example, the first case study, where the rider uses their leaning forward posture to increase engine support, was inspired by the challenge of riders using a throttle or on-screen buttons to access the engine support that, at times, can distract the user from the experience of cycling (Dancu et al., 2015; Johnson & Rose., 2015). Furthermore, following the teachings of Norman (2009), throttles and on-screen buttons are a missed opportunity when whole-body interaction can further the experience of integrating the body of the rider and the system—enabled by the rider moving in sync with the system to amplify the sensation of becoming one with the system. The second case study, where the rider and the eBike work together to cross traffic lights on green, was inspired by the challenge of eBike riders being more prone to accidents at intersection crossings than regular bikes (Langford et al., 2015; Petzoldt et al., 2017; Yang et al., 2018). The third case study, where I derived peripheral awareness as a neurological state to regulate engine support and assist the rider to react faster to changes in the environment, was also inspired by the challenge of eBike riders being more prone to accidents at intersection crossings.

eBikes offer an exciting opportunity for riders as they can invest as much physical effort as they wish and they can also choose when and how much engine support to actuate. Secondly, the rider is using whole-body interaction to invest physical effort and operate the system. This is particularly interesting to further the notion of integrated exertion, due to the correlation between the visual and sensory experience of the rider cycling, which in turn, can contribute to dissolving the presence of the eBike as a tool and enable the rider to become one with the system (De Preester, 2011; Krüger et al., 2017). For HCI practitioners eBikes offer various means of modification and are easily accessible, inexpensive, and finding participants that have experience eBike cycling is straightforward. For my case studies, I selected eBikes as they fulfil the exertion aspect of my research where the user can choose how much physical effort they wish to input while using their whole-body to operate the system, and also because it fulfils the integration aspect due to the flexibility to modify what data is used to regulate engine support towards exploring integrated exertion.

In what follows, I present related work in HCI around cycling, eBikes in HCI and also the societal opportunities that designing with eBikes offers.

Cycling in HCI, experiential aspects of exertion and cycling

Previous work on cycling and HCI has focused on the experiential aspects that exertion and cycling can offer. For example, Rowland et al. (2009) explored mobile phone–based app experiences for cyclists using GPS, concentrating on the enjoyment of cycling. They concluded that, '[bike] design has to respect the distinctive nature of cycling as a mode of transport and needs to carefully interweave moments of interaction with it'. Bolton et al. (2014) combined virtual reality with an exercise bike to simulate users cycling down a virtual street while throwing newspapers, which resulted in an immersive exergame. In the classroom, exertion and cycling have also been explored to support learning (Al-Hrathi et al., 2012), using the bike as an input controller. These works approach exertion and cycling from a ludus perspective, offering structure to users in the experience. However, HCI practitioners can also approach exertion and cycling from a paidia perspective, focusing on promoting improvisation and unstructured play (Lucero et al., 2014). For example, Landin et al. (2002) combined sound elements with cycling on their 'iron horse', which is a bike that makes horse-like sounds when cycling. Another example is the use of LEDs in the bike spokes by riders to promote self-expression while cycling (Goldwater, 2010).

These works highlight that technology can support the experiential aspect of cycling and exertion. Despite the fact that cycling seems to offer various benefits, little exploration has taken place into the use of technology to design for supporting the experiential side of cycling. My work can make a contribution to this by using eBikes to explore different integrations with the exertion body and, in turn, facilitate new cycling and exertion experiences.

Cycling in HCI, whole-body interaction in exertion

Previous works that have focused on whole-body interaction in exertion experiences suggest that limiting the use of screens as a medium to provide feedback to the user during the experience can facilitate users to be more aware of their soundings and their pulsating bodies (Marshall & Tennent, 2013; Mueller & Isbister, 2014; Ståhl et al., 2016). This has led others to explore offering feedback to users beyond the screen and directly on the body, such as using heat and LEDs to offer a guiding meditative experience (Ståhl et al., 2016). Maeda et al. (2005) used galvanic vestibular stimulation to deliver an electrical current to the user's mastoid bone behind the ear to facilitate a sensation of vertigo; the electrical current was synchronised to the rhythm of a song to create an entertaining experience. In this line of work, electrical muscle stimulation has been used in mixed-reality games to offer player feedback according to their whole-body interaction in the game, such as offering a counter force by actuating and causing the user's arms to repulse from a virtual force field (Lopes et al., 2017).

These works highlight a means of providing feedback directly on the user's body within the context of the experience and facilitate novel whole-body interactions, furthering the idea of users interacting freely in the environment and not being constrained by a screen. To this end, this area offers opportunities for exploration, in particular when it comes to considering ways to offer feedback to the exerting body without screens, an area my work can contribute to by exploring the whole-body experience of cycling through an integration approach.

eBike riders are more prone to injury

When comparing eBikes to regular bikes, eBike riders are more prone to injury, especially at traffic light intersection crossings (Fishman & Cherry, 2016; Petzoldt et al., 2017). It appears that this is due to riders accelerating the engine to catch the next light on green and losing awareness of what is happening in their periphery (Petzoldt et al., 2017; Weber et al., 2014; Zhang & Wu, 2013). Various studies have shown that eBikes infringing on traffic lights is a common problem worldwide (e.g. China, 61% (Yang et al., 2018), United States, 70% (Langford et al., 2015), Austria, 36% (Brezina & Hildebrandt, 2016), Brazil, 38% (Bacchieri et al., 2010) and Australia 37% (Johnson et al., 2013)). This societal challenge offers various opportunities for exploration, for example by exploring ways in which the eBike can respond to the exerting body to support the rider, by considering how eBikes as co-operative partners can help riders to catch green lights and by considering how eBikes can assist the rider to more safely navigate the environment. My work explores, through an integrated exertion approach, each of these opportunities to contribute to this societal challenge.

Research opportunity

The intersection between exertion (Mueller et al., 2011) and human–computer integration (Farooq & Grudin, 2016) offers an interesting and unexplored design space that I call 'integrated exertion'. This literature review has shown that currently there is limited design knowledge on how to analyse and design integrated exertion experiences that use enacting systems. The review has also shown opportunities to explore integrating the exerting body with an eBike to make cycling safer.

My work focuses on addressing the gap in knowledge that integrated exertion offers, inspired by the societal challenges that eBike riders encounter, in order to explore different forms of integration with the exerting body. I believe this is important, as integrated exertion can have profound implications for future exertion experiences that use technology to support the user whether for health, work or play.

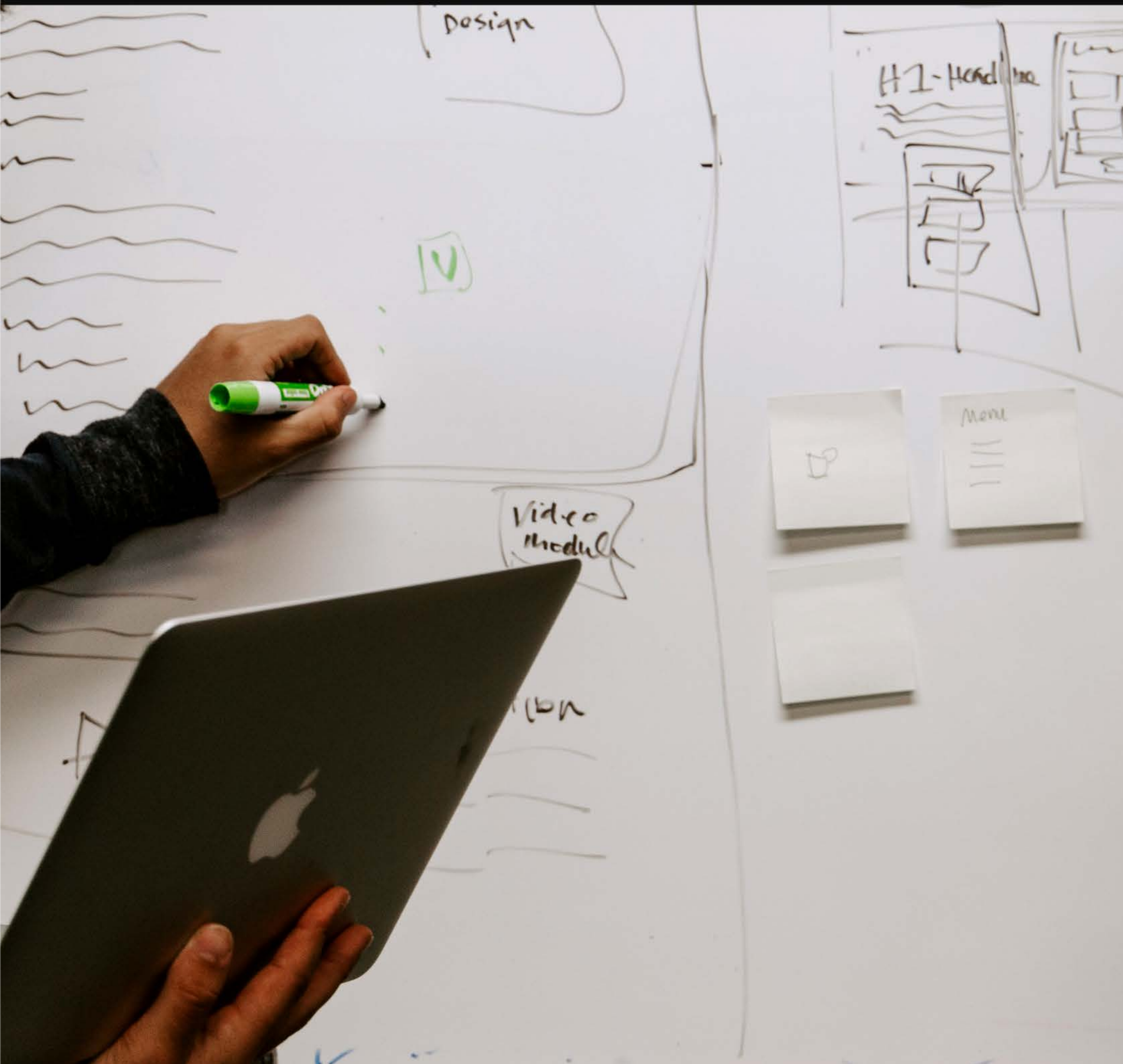
I begin addressing this gap in knowledge by answering the research question:

How do we design integrated exertion experiences?

CHAPTER 3

Methods

Researching integrated exertion.



CHAPTER 3 – Methods

This thesis includes the design and evaluation of three prototypes that serve as research vehicles to understand the design space that the intersection between human–computer integration and exertion offers. In this chapter, I introduce the various research methods I used in the process of answering my research question.

Ethics approval

Each of my studies were approved by RMIT University's College of Human Ethics.
Case study 1, Ava the eBike: CHEAN A 0000020291-07/16. Case study 2, Ari the eBike CHEAN A 21422-05/18. Case study 3, Ena the eBike CHEAN A&B 22071-03&04/19.

Research through design

Used in all case studies
Research through design (RtD) facilitates designers and researchers to design for a future state through an iterative process deriving new knowledge by learning from and iterating the state of the design artefact (Gaver, 2012; Zimmerman et al., 2007). RtD artefacts are designed as objects of enquiry into a probable future (Gaver et al., 2003), for example in my case by designing integrated exertion systems that use different data types to facilitate the experience of integration. The learnings from each of my prototypes were carried over to the next as a way for me to transfer design knowledge gained through this iterative process. Interestingly, in RtD designers and researchers are not necessarily focused on creating a fully developed system. Instead, they are concerned with the why and the how of users interacting with the artefact towards understanding how to design for a future state. The reason for this is that by obtaining this knowledge, designers and researchers can begin to understand the considerations and implications around designing for this future state and subsequently begin exploring the consequences that their future states can bring to the world (Fallman, 2003). Importantly, in RtD the outcomes of the investigation are not only design artefacts but the accompanying insights, reflections and design strategies towards designing for this future state (Gaver, 2012; Koskinen et al., 2011). For example, previous works have utilised RtD to generate theoretical contributions (Márquez Segura et al., 2013; Mueller et al., 2011) and also to explore future systems resulting in design strategies (Andres et al., 2015; Jensen et al.,2015).

Cross (Cross, 1982) suggests that designers can consider a key research question to study when taking an RtD approach, such as 'How would you design an <X>?'. I followed this approach by formulating the research question 'How do we design integrated exertion experiences?' and with each of the case studies I explored different data types to integrate with the exerting body. Through this approach, in my studies I facilitated a design process where I could derive design knowledge from making and studying each of the prototypes in relation to how users interacted with the integrated exertion system. The results from each study were published at a peer-reviewed top-tier conference and these publications report theoretical design knowledge to inform the future state that integrated exertion offers.

Methods used

The focus of this thesis is to create a research framework in relation to how to design for integrated exertion and how to understand the resulting user experiences. As such, a qualitative approach to investigate the user experience that integrated exertion offers is well suited, because it allows the investigator to use exploratory techniques to gain an in-depth understanding of the user experience (Wrigley et al., 2010). In HCI, qualitative practice can be embedded throughout the design process, from interviewing potential users of the system to understand how they currently interact with systems, to co-designing prototypes with adjacent domain experts, to studying and analysing the prototype (Creswell & Creswell, 2017). More specifically, a qualitative approach involves the collection of subjective, open-ended data with the goal of facilitating researchers to study such data to develop a set of common and recurring themes (Creswell, 2013).

In order to investigate my research question, I employed the following methods:

Data collection: Semi-structured interviews

Used in all case studies
Semi-structured interviews provide researchers with a method of capturing qualities of the user experience focusing on how users interact with a system, as such qualities cannot often be measured through quantitative data (Blandford, 2013). During interviews, users may share stories about their experience with the system. These retrospective descriptions offer researchers insights into the user experience and reveal human–system relationships, likes, dislikes and wishes resulting from users' interaction with the system (Corbin & Strauss, 2014). These valuable insights serve to inform future themes later in the process.

A benefit of semi-structured interviews (as opposed to structured interviews) is that they offer the researcher the opportunity to select questions during the interviews such that they support the conversation with participants, rather than having to follow a structured script (Blandford, 2013). In light of this, I recorded in Case Study 2 (Chapter 5) data in relation to the system increasing engine support and in relation to traffic lights' locations. This data was visualised and shown to the users during the semi-structured interviews as an artefact for reflection, where the visualisation facilitated the participant to tell, from their own perspective, what had occurred during those moments. As this was engaging for participants, and also proved useful as a tool to learn more about their experience, I utilised the same approach in Case Study 3 (Chapter 6), where I recorded EEG data from participants interacting with the system and offered this as a visualisation during the interviews to invite further comments and reflection. This data about the user's experience in the form of a visualisation served as a complementary artefact of enquiry into participants' user experience during semi-structure interviews.

Data collection: Explicitation approach

Used in Case Studies 2 and 3

The explicitation approach (Vermersch, 1994) is a retrospective interview technique that seeks first-person accounts and is often employed immediately after an experience has occurred. One of the benefits is that interviewers ask questions in relation to specific moments of the experience in a chronological order of events to learn about how the experience unfolded from the participant's perspective. This approach allowed me to capture in situ experiences including tactile details which often rapidly decay in the user's memory (Gallace & Spence, 2009; Obrist et al., 2013). To utilise this approach and capture user experience details, I designed the cycling course in Case Study 2 (1.2 kilometres) and Case Study 3 (1.5 kilometres) so that participants could cycle the course once or twice and come back to the starting point for interviews before heading out to complete more laps. This offered me the opportunity to use the explicitation interview approach to capture the experience 'as it happened' between laps, and it also allowed participants to reflect and be observant of their experience when cycling the next lap.

Data collection: Design thinking

Used in Case Study 2

Design thinking (DT) provides a way to approach a problem from a design-oriented perspective by considering it holistically; for example, by enquiring about a user's thinking processes, feelings and activities performed while completing a task (Dorst, 2011). This approach can assist HCI practitioners in discovering details through the experience, highlighting challenges and opportunities, and overall offering a deeper end-to-end understanding of the experience (Stickdorn et al., 2011). In my work I employed a DT approach in Case Study 2 to gain a deeper understanding of rituals and practices between riders and their bikes. This is discussed in greater detail below.

In Case Study 2, I conducted two DT sessions as part of the inception of the study with the cycling community from within our research lab, which had riders from varied backgrounds such as industrial design, computer science, sustainable transport and HCI. I utilised a series of exercises to map out a day-in-the-life of the rider, focusing on the moments of interaction with the system, and preparing and packing away the system to capture nuances and rituals about the user experience. By drawing from their expertise to discuss, sketch and derive ideas, I was able to capture a set of design considerations to inform the first iteration of the prototype.

Data collection: Field deployment

Used in Case Study 1
Field deployments facilitate users to live with a system in order to investigate the system in real-world situations (Chamberlain et al., 2012). This approach allows researchers to focus on the context of use in relation to the participants' everyday practices and is often followed by interviews as a means of enquiry into participants' experience (Brown et al., 2011). In HCI, field deployments have been used to study novel technology, focusing less on the technical feasibility and more on the user's understanding and usage of the system (Gaver et al., 2013; Kalnikaite et al., 2011). In my work, I experimented with this approach in the first case study by deploying the prototype to participants' homes for two weeks. While this approach yielded interesting results around how participants used the system in the context of their routine, it also lacked opportunities for me to observe directly how participants used the system, which in turn could have informed in situ questions to further enquiry into the user experience.

Data collection: Likert scale questionnaire (quantitative method)

Used in Case Study 1
I used the Sports Climate Questionnaire (SCQ) (Deci & Ryan, 2007) to investigate the autonomy support perceived by the user from their own bike, in comparison with my prototype. The SCQ has six questions, each with a seven-point Likert scale, where 1 = strongly disagree and 7 = strongly agree. Participants completed the questionnaire first in relation to their own bike and second in relation to my prototype after experiencing it. This questionnaire was the only quantitative method used and was not with the aim of gaining a significant result (as the sample was too small for that purpose), but rather to paint a comprehensive picture complementing the semi-structured interviews.

Data analysis: Thematic analysis

Used in all case studies
Qualitative analysis focuses on deriving meaning from the data in relation to interactions, context and systems, often in the form of themes (Braun & Clarke, 2006). A theme is considered to be a collection of labels where each label describes something important about the data, often in line with contributing to answering the research question; the collection of labels then leads to a theme in the data. As such, thematic analysis offers a process to derive labels leading to themes grounded in the data in order to study the research question (Braun & Clarke, 2006).

I began employing this approach by familiarising myself with the data in each of the case studies through manually transcribing the audio recordings to text and uploading them to the Nvivo software (Bazeley & Jackson, 2013). I also included photographs and added a short description to each in relation to the context in which they were taken and what they were showing. As a second step in the analysis process, the second author on each case study and I independently added labels to the data, describing important aspects that each of us observed. Next, I worked together with all my co-authors on each case study to review and compare our labels, using a mind map to chart potential themes and their relations. This process was followed by various meetings where I refined the themes. The themes and my experience in designing each system led to practical design tactics within each case study to design for the given integrated exertion context.

Summary

In this chapter I have presented the methods used to investigate each of the case studies. Primarily I took a qualitative approach using RtD to iteratively carry over design knowledge through each case study and I also used various data collection methods. Finally, I employed a thematic analysis approach to analyse the collected data. In what follows, I present the case studies (Chapters 4 to 6), describing the implementation of these research methods to answer the research question of this thesis. I also describe the design and development details for each prototype.

Through the implementation and execution of these research methods, I was able to publish each case study at a peer-reviewed top-tier conference. These publications and my experience in conceptualising, designing, building and studying each prototype allowed me to begin iterating on the framework for designing integrated exertion presented in Chapter 7.

CHAPTER 4

Case study 1

Integrated exertion via movement data from the user's body.

CHAPTER 4 – Case Study 1: Ava The eBike

In this chapter I present my first case study, Ava the eBike. In this work I explore creating an integrated exertion system that acts on the user's movement data to support the exertion experience. Ava acts on the user's leaning forward body position to synchronously increase engine support. This is achieved by programming the gyroscope on a smartphone attached around the rider's chest and wirelessly connected to an Arduino and the eBike's engine controller. The study of Ava let me begin exploring how an integrated exertion system can extend the user's physical abilities by offering engine support to go faster, controlled synchronously with the user's body. This work resulted in themes and design tactics to analyse and create superpower-like experiences in integrated exertion.

In this case study I explore my primary research question by investigating the sub-research question: *How do we design integrated exertion systems that can act on the user's movement data to support the user experience?*

Table 7: Case Study 1 summary.

Publications	**Andres**, J., De Hoog, J., von Känel, J., Berk, J., Le, B., Wang, X., ... & Mueller, F. (2016, October). **Exploring Human: EBike Interaction to Support Rider Autonomy**. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts* (pp. 85–92). ACM. https://doi.org/10.1145/2968120.2987719 **Andres**, J., de Hoog, J., & Mueller, F. F. (2018, October)**. I had super-powers when eBike riding Towards Understanding the Design of Integrated Exertion**. In *Proceedings of the 2018 Annual Symposium on Computer–Human Interaction in Play* (pp. 19–31). ACM. 10.1145/3242671.3242688
Ethics approval	CHEAN A 0000020291-07/16
Research question	How do we design integrated exertion systems that can act on the user's movement data to support the user experience?
Data type	Movement data
Produced outcomes	Ava the eBike gives riders a sensation of a superpower–like experience, as Ava acts on the bodily inclination of the user in real time to offer or stop offering engine support; as such, riders expressed the sensation of accessing extra physical ability through the engine directly from their body.

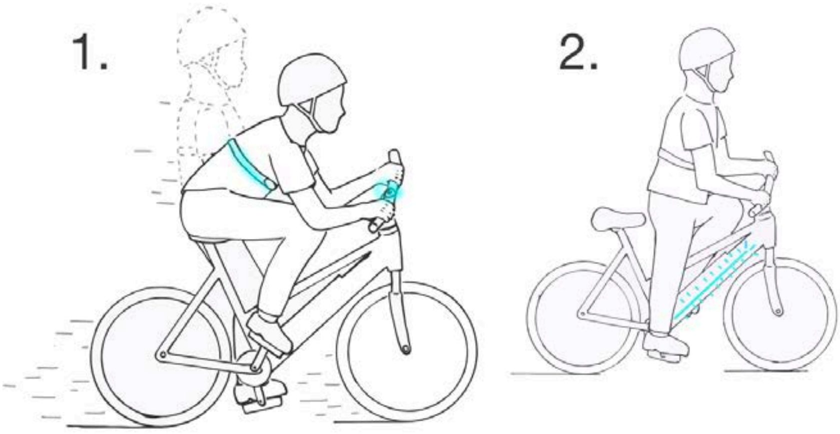


Figure 4. Ava senses the rider's posture to activate: 1. the eBike's engine support according to the rider's torso angle; 2. when going slowly (resuming cycling) activating LED safety hazard lights.

Ava the eBike

Ava uses the rider's body in two ways: (1) As the user leans forward as a result of trying to invest more physical effort such as when aiming to cycle faster or climbing a hill or embracing speed when going downhill. The angle of the rider's body as it leans forward serves as a control mechanism to activate the engine's support and go faster. As the rider leans forward and the eBike accelerates, I built in an acceleration sound to amplify the sense of acceleration which can be turned off if desired. (2) As the rider stands up to pedal to resume cycling, Ava activates LED hazard lights to make nearby vehicles, bikes and pedestrians aware of the eBike, thereby contributing to the rider's safety.

Why leaning and standing up?

I chose to experiment with these three features because:

1. Using the leaning forward to accelerate enabled me to explore a more integrated and physically engaged experience when the rider accesses the assistance beyond using throttles, as throttles only require a twist of the wrist. I noticed in my previous study (Andres et al., 2016) that riders usually lean their bodies forward to embrace speed in cycling. This also occurs in different sports, such as surfing and skating, and this led me to explore the rider leaning their body forward so that Ava gradually accelerates. Leaning is an alternative to using the throttle and could contribute to helping the user remain focused on the enjoyment of cycling, rather than on operating controls.

2. Sound plays a key part in the sensory experience of the rider and so I used sound to support fantasy aspects of accelerating. This is similar to how the wind becomes louder in the rider's ears when cycling faster and is also similar to the

changing sounds of accelerating mechanical vehicles such as cars and motorbikes. I wanted to leverage this sensory experience to amplify the sense of acceleration with an acceleration sound.

3. I wanted to enhance safety when resuming cycling. eBikes are often slightly heavier than standard bikes and when the rider resumes cycling while standing up to pedal, they can become 'wobbly' (Johnson & Rose, 2015). Ava takes into account the speed of the eBike and the rider's posture to interpret this as 'resuming cycling' and activates LED hazard lights located on the sides of Ava's body.

These three features emerged from my previous work (Andres et al., 2016), which focused on implementing the system. In this chapter I focus on studying the system.

Ava's technical aspects

I modified two eBikes (a cruiser and a hybrid) with the same functionality in order to offer participants a choice between eBike geometries and also to accommodate a wider range of body sizes. These two models offered a familiar architecture to modify and very low motor noise.

Ava Cruiser is built around an original Dillenger brand eBike, model OspreyLight, with 250W nominal power (DillengerAU, 2015). I used a Raspberry Pi 3 Model B as a processor to augment Ava. Riders can accelerate by: a) using the throttle; or b) leaning forward. The angle of the leaning posture determines the intensity of the power applied to the motor. The leaning forward is designed so that riders accelerate momentarily; however, they can remain in this posture to enjoy acceleration to the fullest. The bodily acceleration angle is calculated with a smartphone gyroscope sensor worn tightly on the rider's chest. This is placed in a custom-made elastic pouch. The gyroscope is calibrated upon turning on the system and it records the current posture of the rider as the rider is sitting straight and not yet leaning; users of Ava were briefed on this intialisation procedure. The gyroscope sensor data is interpreted by an electronic control unit (ECU), which uses the data to control both the power assistance and the sound emitted through the speaker. For example, for safety, when leaning forward, one linear Hall effect sensor is mounted on the eBike's handlebar to detect handlebar displacement so that when the rider is sharply turning, bodily acceleration is disabled. Furthermore, two Hall effect sensors are used to detect when the rider is resuming cycling from a stopped position; wheel and pedal rotation detection is achieved by mounting the sensors on the pedal system and front wheel. Ava has LEDs that pulsate as hazard lights when the rider is resuming cycling (Figures 5 to 8).

Figure 5. Ava Cruiser and Ava Hybrid.

Ava Hybrid offers the same functionality as Ava Cruiser, but it uses the Dillenger Easy step over model (DillengerAU, 2016). Ava Hybrid's performance frame offers a sporty look and feel, although it provides the same 250W nominal power.

I designed my system to harness the eBike's battery power (avoiding the need for additional power sources and cabling). I used Ava's Cruiser voltage (28V) to power the LEDs (12V), sound (5V) and main board (3.3V). DC-DC step-down converters were used to achieve the required voltages. This power system was also used on Ava Hybrid but it offered 42V, therefore I had to use a one-buck converter to lower the voltage stream down to 28V.

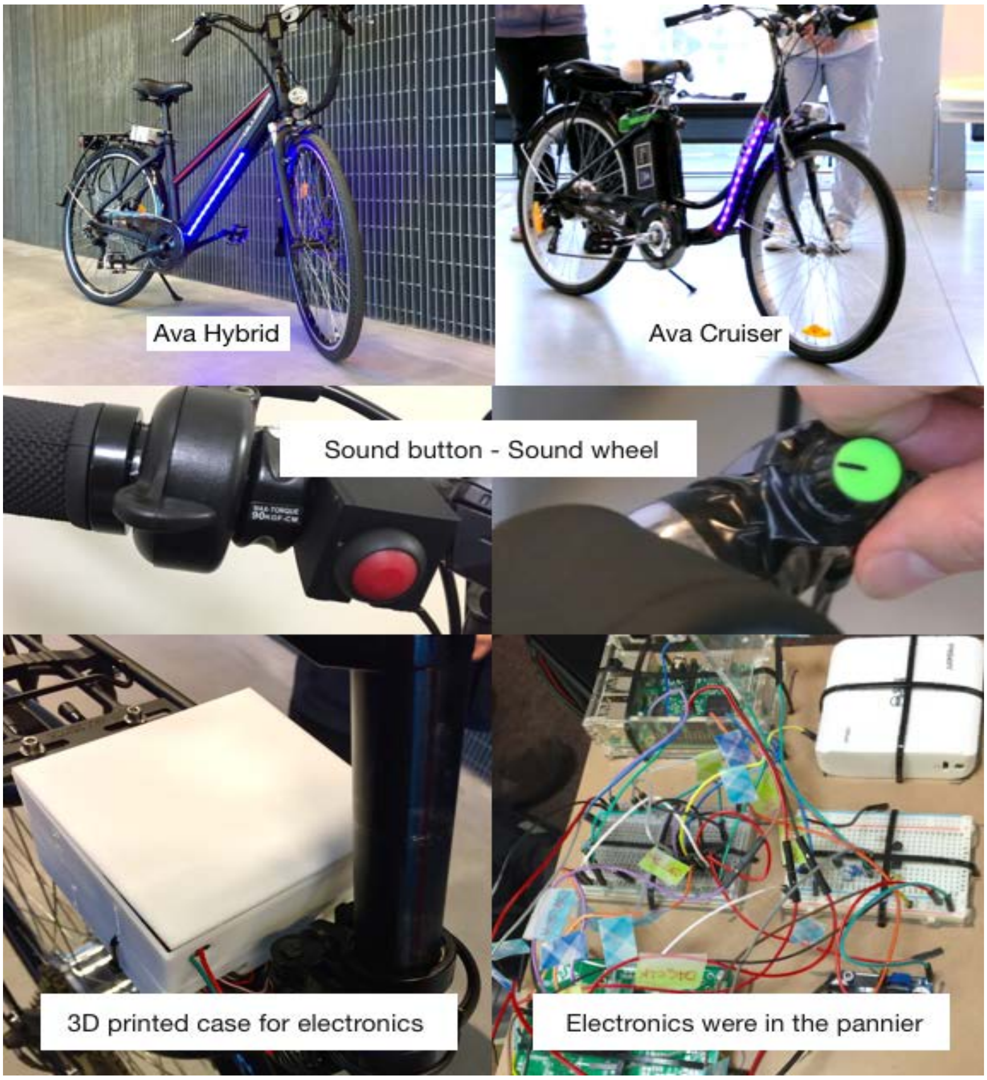


Figure 6. Ava Cruiser and Ava Hybrid offered the same functionality – hardware differences shown above.

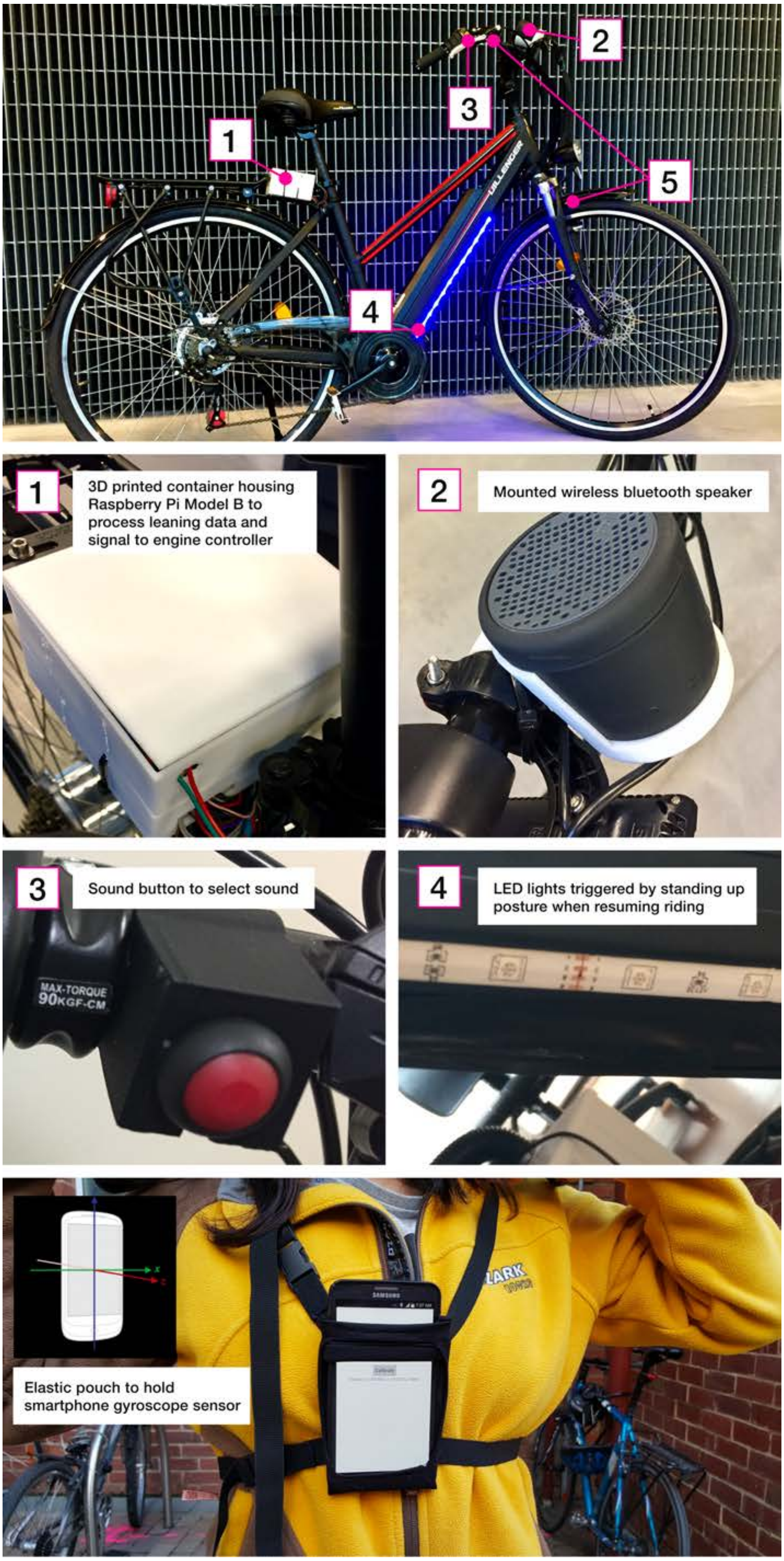


Figure 7. Shows the eBike components.

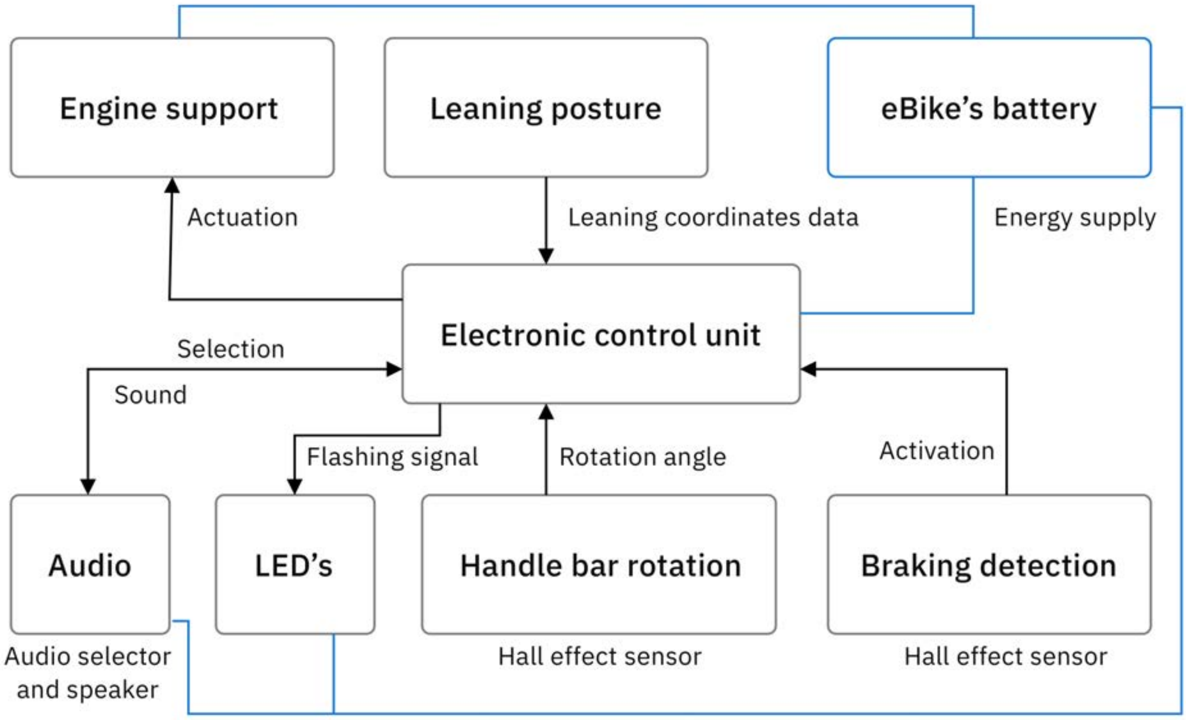


Figure 8. High level schematic of Ava's components.

The specific functions are described as follows:

- The rider's posture is detected via a smartphone's gyroscope sensor using a custom-built Android app that via Bluetooth communicates with the electronic control unit.
- Displacement of the handlebars is detected by a linear Hall effect sensor mounted on the eBike for safety to disable engine support.
- The gyroscope data is processed by an electronic control unit to control both the engine support and audio playback.
- LEDs are activated when the rider is resuming riding, by using the coordinates from the standing up position.
- The sound selector switch toggles between available sounds.
- The eBike's battery supplies energy to all the components.

Study

To answer the research question 'How do we design integrated exertion experiences?' I conducted the following study towards understanding the user experience of cycling with Ava.

Once participants accepted my invitation, they chose which eBike they preferred to use, Ava Cruiser or Hybrid. I first showed participants how to adjust the phone in the pouch and the eBike seat for their comfort. I conducted a study with 22 eBike riders in the following manner:

1. Participants took the Sports Climate Questionnaire (SCQ) in relation to their own eBike. This questionnaire was chosen as I hoped it would give me insight into how Ava might affect the user's perceived autonomy support (Deci & Ryan, 2007).
2. Participants hosted Ava for two weeks at their home and noted down thoughts about their experience so that these notes could be used in the semi-structured interviews to reflect on their time with Ava. Participants repeated the SCQ in relation to using Ava after the two weeks.
3. Semi-structured interviews were conducted at the end of the two weeks in regards to the rider's experiences.

Participants

I recruited 22 participants (F=10 and M=12), aged between 24 and 55 years old (M=36.4 and SD=9.4) from a medium-sized city in the Asia-Pacific region. Participants were recruited through both emails and advertisements. Participants came from the university (7), from the local council (8) and from among colleagues (7). All participants had been eBike riders for between three months and three years, as shown below (Table 8).

Table 8: Participants' eBike cycling experience.

Number of Participants	**eBike cycling experience**
10	3–6 months
7	7–18 months
5	19–36 months

Data collection

Firstly, I collected participants' responses to the SCQ, which has six questions, each with a seven-point Likert scale, where 1 = strongly disagree and 7 = strongly agree. The two-phase questionnaire is shown in Table 2. Secondly, I conducted semi-structured interviews following the Kvale (Kvale, 2008) approach; the semi-structured interviews were audio-recorded.

Data analysis

I employed a thematic analysis approach to the data (Braun & Clarke, 2006). The interviews were transcribed for qualitative analysis, where two researchers independently consulted their own copy of the transcripts. Each researcher created their own codes to capture and group points that were interesting using Nvivo software. This was followed up with multiple meetings where the researchers viewed each other's codes, refined their analyses and reached consensus on the final codes. For the questionnaire, the answers for the participants' own eBikes and for Ava were charted (Figure 9). The SCQ was used not to reach statistical significance, but rather to paint a comprehensive picture complementing the interviews. The chart, codes and transcripts facilitated the researchers' derivation of the main themes.

Results

I now articulate the results. Participants' names have been changed for privacy. Figure 9 shows the participants' responses to the SCQ questionnaire for their own eBike (M=4.4 and SD=0.4) and for Ava (M=4.9 and SD=0.6). Table 9 shows the questionnaire questions.

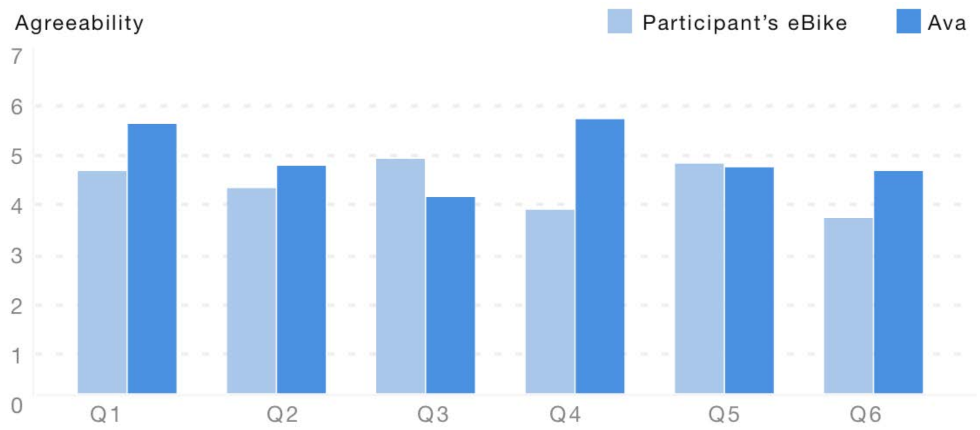


Figure 9. Participants' questionnaire answers.

Table 9: Reworded SCQ questionnaire questions.

Q1	I feel that my bike provides me with choices and options.
	I feel that Ava the eBike provides me with choices and options.
Q2	I feel understood by my bike.
	I feel understood by Ava the eBike.
Q3	My bike assists me in feeling more confident in my ability to cycle.
	Ava the eBike assists me in feeling more confident in my ability to cycle.
Q4	My bike encourages my curiosity when cycling.
	I feel Ava the eBike encourages my curiosity when cycling.
Q5	My bike responds to how I would like to cycle.
	Ava the eBike responds to how I would like to cycle.
Q6	My bike appears to understand how I cycle before suggesting how to ride.
	Ava the eBike appears to understand how I cycle before suggesting how to ride.

Themes

I present the results in the form of themes with a total of 138 units coded. The results are organised to reflect how the user experience unfolded.

Theme 1: Interacting with Ava

This theme describes 48 units and it has two categories: *Cycling Ava was engaging* (22 units) *, and Ava supported natural interaction (26).*

T1.1 Cycling Ava was engaging

Overall, participants stated that they enjoyed cycling Ava. Participants exerted themselves while cycling and used their entire body as afforded by my design. They applauded the system for providing them with an engaging experience. For example, Carl said Ava was 'exciting', Tilly said 'I felt pretty good cycling Ava' and Lisa said 'I felt it was a pleasant and simple way to accelerate'. Besides the positive experiences we also learn from negative experiences in themes three and four. In Q1 participants scored Ava higher than their own eBike when it came to how they perceived that Ava provided them with choices and options. This appears to support the rider's autonomy and their engagement with Ava.

T1.2 Ava supported natural interaction

It appears that Ava was able to support a more natural interaction by taking advantage of in-cycling actions, such as leaning forward when wishing to go faster.

This seemed to allow participants to access the assistance of the engine while remaining focused on the cycling experience, rather than using a manual controller. For example, Maria mentioned: 'It is like when you drive a car, you know how to change the gears, and as you become more experienced and familiar with it, you do so automatically without even looking or thinking, as if sensing the revs of the car triggers you to switch gear, this can be an enjoyable experience'. Byron said: 'When I was learning to use my eBike, I would get caught up with some of the controllers like adjusting the speed assistance threshold when cycling. When learning to cycle with Ava I didn’t have to think about controllers, that’s a good thing'. These comments align with Q6 in the questionnaire where participants rated Ava higher than their own eBike. The leaning forward appears to offer more physical engagement than using a throttle and is also an enjoyable way to access acceleration.

Theme 2: Experiencing Ava

This theme describes 56 units and it has three categories: *Ava was more experiential than participants’ eBikes (18), Ava facilitated make-believe (22), and Cycling Ava felt like performing (16).*

T2.1 Ava was more experiential than participants’ eBikes

Participants reported that they found Ava to be more enjoyable than their regular eBike (18 units). For example, Rob described Ava as 'more fun' than his regular eBike and Maria explained that 'It was fun using my torso to accelerate'. This more enjoyable experience appeared to stem from the fact that Ava was considered 'less serious' than a regular eBike. Carl commented: 'You see, I think about my eBike as a tool to help me get places, but Ava is more like an experiment and because of that seems more enjoyable'. This finding is echoed by the questionnaire results: participants reported in Q4 that they found that Ava supported their curiosity more than their regular eBike when eBike cycling. I believe this contributed to participants’ experiences with Ava being more experiential.

T2.2 Ava facilitated make-believe

Participants reported that they felt that Ava was able to facilitate a sense of make-believe (22 units). For example, participants described that when they experienced the engine power that Ava offered by accessing it with their body, it appeared to facilitate the feeling of a 'superpower'. Lisa said: 'When using my torso, it’s like the power comes from my leaning, and not from the engine, it makes me feel stronger'. This 'superpower' seemed to facilitate a sense of make-believe. Tilly reported that Ava allowed her to imagine what it would be like to be in a motorbike race: 'I like that the power is always there for you. Sometimes when the road is fairly empty, I like to use the body acceleration and take the curves exaggeratedly as if I was motorbike racing'. In Q4 participants scored Ava higher than their own eBike in terms of supporting their curiosity when eBike cycling. This most likely contributed to participant make-believe moments as they appeared to have been more aware of their surroundings, their whole body, the acceleration and the sounds than when cycling on their own eBike. It appeared that the sound Ava made when accelerating supported this notion of make-believe. For example, Tilly said: 'This [the engine power] was particularly fun when using the turbo sound'. Jessi commented 'When I was accelerating to the fullest it reminded me of the tron motorbikes, you go low to go fast'. Participants created moments of 'make-believe' (Deterding, 2016), as known from games, where their exaggeration in taking curves while eBike cycling appeared to support moments of fun fuelled by a fantasy aspect.

T2.3 Cycling Ava felt like performing

Participants reported that cycling Ava felt like 'performing' when other people were around. For example, Jessi experienced that others were watching her as she tried out the leaning forward acceleration and she felt like showing Ava off. Jessi said: 'There is a flat open space where the museum is, when I was accelerating with my body, and the sound came on, people nearby were like, what is that? I kept showing Ava off'. This suggests to me that the environment, together with Ava, facilitated entering a performative mode.

Theme 3: Reduced body control over Ava

This theme describes 26 units.

T3.1 Experiencing reduced body control over Ava

The eBike’s gyroscope did not consider steep inclination off the road and as a result responded sometimes differently to what participants expected. For example, Lisa said: 'I tried a couple of routes with Ava to experiment. I enjoyed at times when the leaning forward to accelerate going uphill did not kick in as it made me work harder'. Lisa’s comment suggests that the inclination off the road when going uphill meant that the rider’s attempt to lean forward to get the extra boost was not recorded. However, Lisa thought the eBike’s failure to accelerate when on steep hills was a design feature to push her towards higher exertion and to gauge her strength. On the other hand, Carl mentioned: 'From my house there is a downhill road towards the park. The first times I was conscious of the increased speed and tried to slow it down; however, over the next times I tested it [Ava] I let the speed increase to see how fast I could go'. This suggests that the inclination of the road when going downhill was interpreted as an intense leaning action, causing the eBike to accelerate even though the rider did not intend this extra acceleration. To this end, participants could use the brakes which switched the acceleration off. In relation to these experiences, Q3 in the questionnaire suggested that participants felt more confident about their ability to cycle with their own eBike than with Ava. This score may have resulted from some of them momentarily experiencing reduced body control as they were getting used to Ava. Participants experienced discomfort and thrill because the experience of momentary reduced body control over Ava appeared to 'disconnect' their body from Ava's, at which point they were conscious of Ava as an object that facilitated cycling – in line with what Heidegger (1954) refers to as ready-to-hand, where the participant was cycling in harmony with Ava while in control and not aware of Ava as an object. In contrast, when Ava momentarily took over, the participant experienced Ava as present-at-hand, where Ava was seen as an object disconnected from their body and no longer moving in harmony, resulting in the rider's attention shifting to Ava from the experience of eBike cycling.

Theme 4: Ava's technology

This theme describes 8 units and it has two categories: *Suggestions for improvement (22 units) , and Hazard lights were not mentioned (0).*

T4.1 Suggestions for improvement

The most common suggestion was related to the charging of the extra mobile phone and the second most common was putting on the elastic pouch that held the phone, because participants were required to loop the stretchable material around their chest. Tilly commented: 'It is not terrible having to put the pouch on, I know it's a prototype, but on a real product I would expect the sensors to be embedded on the helmet or rider's jacket. I take very few steps to unlock my eBike to go, any extra steps should give me a lot more functionality'. It appears that putting on 'wearables' in the form of cycling clothing is a limiting factor towards enjoyment that the design of augmented eBikes needs to take into account. As likely with any bike, people also encountered challenges. For example, Hector found Ava intriguing, but he also had trouble due to his height (1.92m): 'I appreciate the extra boost Ava has in comparison to my eBike, especially when taking off, the body leaning forward is interesting. However, for my height and the size of the eBike frame, I found it hard to use'.

T4.2 Hazard lights were not mentioned

Probably because the lights were more for other people than the riders themselves, the LED hazard lights did not seem to elicit too many responses from participants. For example, Carl said: 'The LEDs did not do much for me'. To gather further responses about the lights, I perhaps should have also interviewed other road users.

Design tactics

I now discuss ways of designing integrated exertion experiences based on my craft knowledge of creating Ava. My experience of experimenting with Ava and the data collected from the study have helped me refine this knowledge. I present seven design tactics aimed at providing designers with practical guidance when designing integrated exertion experiences, especially to facilitate superpower-like experiences.

Tactic 1: Support rider autonomy by allowing the rider to choose when and how much assistance to access.

Derived from themes: *Cycling Ava felt like performing (T2.3) and, Ava supported natural interaction (T1.2).*

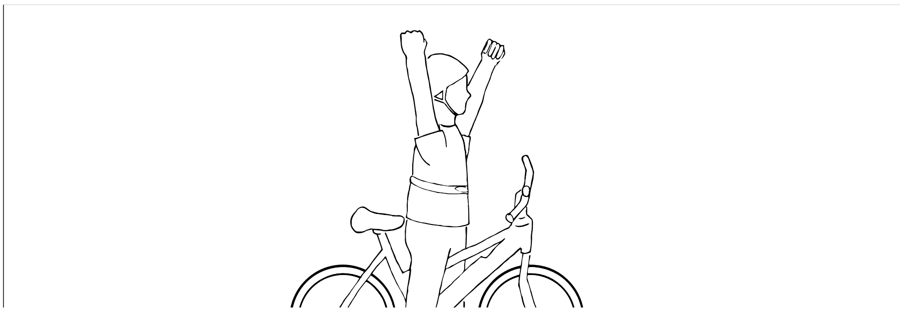


Figure 10. The rider controls when and how much assistance to access; this supports their autonomy during the exertion experience.

With Ava, the rider is always in control of the assistance and can choose when and how much to access. In contrast, with Pedelecs or some exoskeletons the user does not have the same amount of control, because as they get on the Pedelec or wear the exoskeleton, the assistance is active throughout the experience. In themes 1 and 2 participants highlighted that they enjoyed controlling the assistance and it supported their curiosity to ride, as well as offering them an engaging experience.

I draw from embodiment to further describe what made eBike cycling with Ava an engaging experience: 1. the rider's bodily and eBike awareness; 2. the environment; and 3. their cycling skills and assistance control availability. These aspects offered the rider opportunities to be in the world (Dourish, 2004). Examples include cycling down a windy road by moving their torso exaggeratedly while using the turbo sound, or racing others and using their whole body to lean and control the acceleration to go faster. This capacity to control and explore supported the rider’s autonomy and contributed to the rider’s engagement in the experience (Ryan & Deci, 2000).

In practice, this tactic can be applied to the design of integrated exertion and playful experiences where there is a focus on whole-body interaction. The user can experience their body in new ways augmented by technology and discover their surroundings, while gaining bodily knowledge towards controlling the system as their own bodily superpower.

Tactic 2: Promote more natural interaction with the system, higher physical engagement and a higher sensory experience for the user with ongoing actions.

Derived from themes: *Ava supported natural interaction (T1.2).*

Figure 11. Leveraging ongoing actions to interface with the system’s mechanical features promotes natural interaction.

With Ava, the way in which the rider accessed the assistance was by leaning their torso forward. This movement is often used to embrace speed and was chosen since moving the torso in cycling is an ongoing action as it is a recurrent movement in the experience (Fullerton, 2014). As a result, the recurrent movement facilitates the user to build muscle memory and can promote ease of interaction with the system. In theme 2, participants reported that leaning their torso for accessing the assistance appeared to offer more natural interactions with the system, rather than using a throttle. Also in theme 2, participants highlighted that leaning to access the assistance could offer higher bodily engagement, which in turn afforded a stronger sensory experience to the rider when leaning to access the assistance due to their body schema including the eBike (Berlucchi & Aglioti, 1997).

I could have used a foreign movement to accelerate, such as spreading the legs, but this would not offer the rider the opportunity to draw from their previous cycling experiences, nor would it tap into their muscle memory. Considering the ongoing actions and feature purpose to map to are important details of the user experience which, when mapped, can promote or hinder integrated exertion between the user and the system.

In practice, this tactic can be used to design novel human–system augmentations in superhuman sports (Kunze et al., 2017) or exertion games (Mueller & Young, 2017), by reflecting upon the ongoing actions performed by a player within a game context. This reflection focuses on identifying the ongoing actions within the game context towards integrating supporting technology into the ongoing actions. In this case, technology offers the player new opportunities to interface with the system while remaining focused on the game experience.

Tactic 3: Design for zero body disparity to facilitate the rider to be one with the system.

Derived from themes: *Experiencing reduced body control over Ava (T3.1) and, Cycling Ava felt like performing (T2.3).*

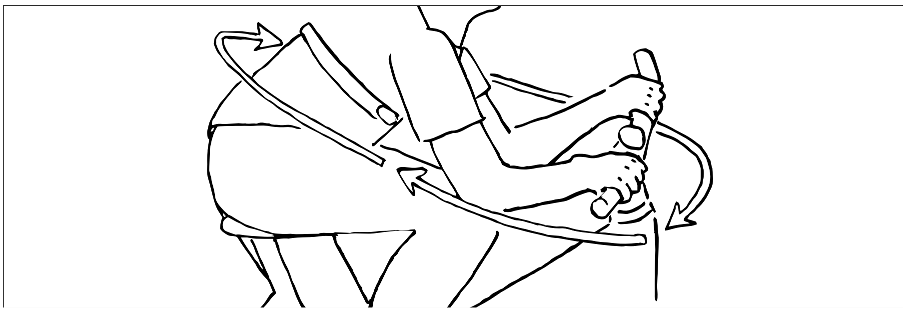


Figure 12. The rider uses their whole body to control the actuation and experiences the sensation of acceleration during eBike cycling.

This study with Ava considered the use of the whole body to physically engage with an actuation-enabled system. Design I considered to be physical disparity which refers to the distance between the user's input and the systems output (Mueller, 2017). For example, the distance between a laptop's touch pad where the user inputs and the resulting movement of the cursor on the screen where the user can acknowledge the output is 20cm. An important aspect is that the acknowledgement of the output is often through eyesight in screen-based systems such as laptops, desktops, tablets and smartphones, and also on gestural interaction systems such as Wii and Xbox Kinect.

In Ava's case, the distance between the user's input by leaning and the system's acceleration output is zero body disparity. The reason for this is that the user can experience the sensation of the output instantly and directly through their whole body, which appears to facilitate users experiencing their body as play (Mueller, 2017). In line with facilitating players to experience the output instantly and directly through their whole body as a result of their whole-body interactions are mixed-reality games that utilise force feedback (Lopes et al., 2018). This allows the player to interact with the environment using their whole body, as well as experiencing their whole body as play when experiencing the feedback.

In practice, to design for zero body disparity designers can focus on whole-body input and facilitating instant and direct sensations on the player's whole body as a result of their interactions. This appears when controlling a system's assistance to give the player the ability to control it as if it were part of their body. It also frees the player from attending to alerts, scores and notifications on a screen.

Tactic 4: Fine-tune the assistance response to be gradual yet strong to offer a more enjoyable experience.

Derived from themes: *Experiencing reduced body control over Ava (T3.1) and, Suggestions for improvement (T4.1).*

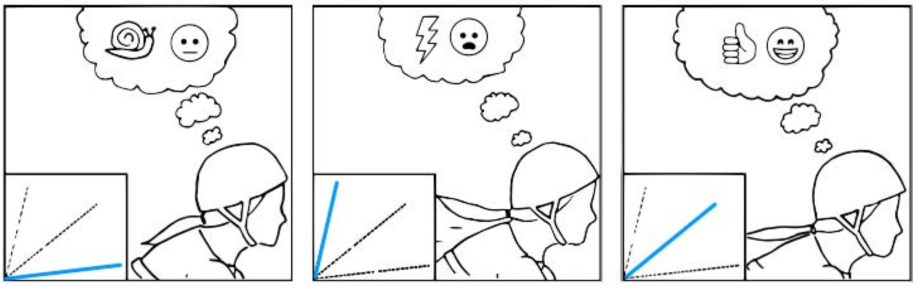


Figure 13. The system's response intensity to the user's interaction can yield different experiences.

When evaluating the assistance response from the system, I fine-tuned by trial and error, conversing about the research team's experiences after trying out Ava. When Ava responded too strongly by supplying a high amount of assistance with minimal leaning, it made the experience feel jerky and uncontrollable. Conversely, when Ava responded with minimal assistance as the rider was leaning forward, it brought the perception that the battery was either low or the engine assistance was weak. For this reason, I experimented by fine-tuning the response to be above medium, where the system is perceived as strong, yet with a gradual progression of response as the rider leans forward – this I believe can contribute to the user perceiving the power to be under their control, and hence it is their superpower.

In practice, fine-tuning the system's response to the user's bodily movement during the experience can be used as a way to communicate and facilitate different sensations to the user according to the situation. For instance, this tactic can be used in mixed-reality games that use electrical muscle stimulation (Lopes et al.,

2018) where the user experiences the sensation directly on their body according to their whole-body movements.

Tactic 5: Consider amplifying any sensation by engaging other senses to facilitate make-believe.

Derived from themes: *Ava facilitated make-believe (T2.2).*

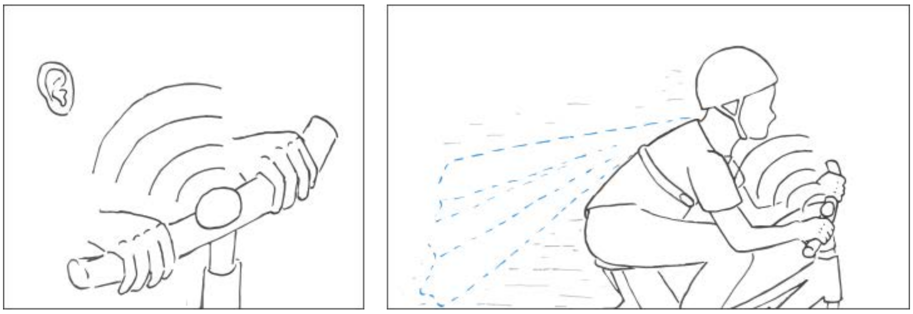


Figure 14. A make-believe moment when the rider imagines they hace superpowers as a result of the amplified sense of acceleration facilitated through audio.

The use of sound allowed riders to amplify the sensation of acceleration as they leaned forward. In particular, the 'turbo' sound was quoted often by participants as they enjoyed how it complemented the experience of accelerating. I could have not used sound or chosen a sound that was not complementary to the acceleration. I believe that the turbo sound working in sync with the acceleration was an important aspect in facilitating make-believe moments (Bogost, 2006; Deterding, 2016), as reported in theme 2, because it amplified the sensation of acceleration while the rider was leaning forward.

In practice, I learnt from other works that engaging other senses in the experience towards amplifying the user's sensation (Kajastila et al., 2014; Pugliese & Takala, 2015) can contribute to the user's experience, for example by igniting performance moments during exertion. Designers can consider engaging with other senses towards amplifying the user's sensation, as this will also contribute to superpower-like experiences.

Tactic 6: Offer momentarily reduced body control without the user's goals in mind (thrill and discomfort).

Derived from themes: *Experiencing reduced body control over Ava (T3.1).*

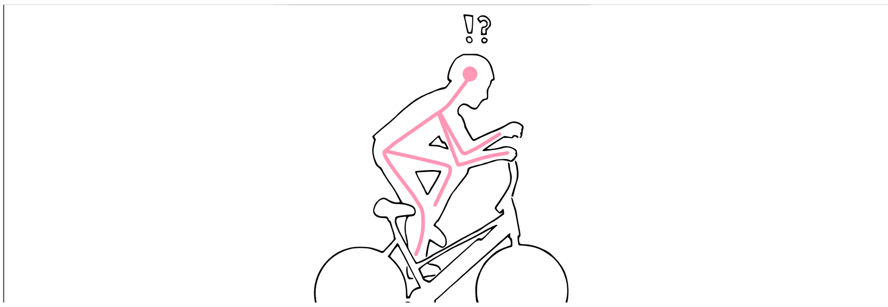


Figure 15. The user can experience their body being disconnected from the system momentarily during exertion.

I learnt in theme 3 that when the rider was climbing uphill and wanted to use the electrical assistance but this was withheld, this was considered a feature designed to challenge the rider's physical limits. When the assistance came on by itself as a participant was going downhill, the participant reported feeling discomfort the first times and after a few times deciding to let go momentarily to embrace the speed. Thrill and discomfort can be conducive to excitement and enlightenment (Benford et al., 2012; Marshall et al., 2011), and in this case resulted in the rider gaining a new perspective on their strength.

In practice, momentarily reduced body control without the user's goals in mind occurred with Ava because participants did not expect the response in the uphill or downhill cases. This element of surprise helped the rider to make a decision on the spot to continue with the discomfort and overcome it, regain control by using the brakes or get off the eBike and terminate the discomfort. This notion of reduced body control over the experience has been used in mixed-reality games that draw from thrill (Kors et al., 2016) to facilitate engaging and memorable experiences. Reduced body control over the experience appears to me an important design resource, as it can engage the user's whole body within the experience. However, I note that in integrated exertion, as most likely users will be moving, offering users the option to regain control would allow them to negotiate the discomfort on their own terms, which in turn would allow them to test their own comfort boundaries and experience thrill.

Tactic 7: Offer momentarily reduced body control with the user's goals in mind (a sense of working together).

Derived from themes: *Experiencing reduced body control over Ava (T3.1) and, Ava supported natural interaction (T1.2).*

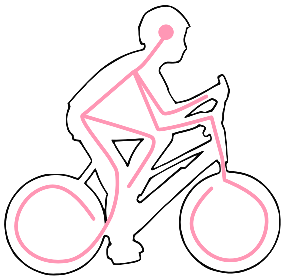


Figure 16. The user and the system can work together by acting on and reacting to each other's actions.

Contrary to tactic 6, in this tactic the rider expects the system to momentarily take over, resulting in momentarily reduced body control for the rider's benefit. For example, the cyber-physical Pedelec (Sweeney et al., 2017) accelerates when pollution ahead is high to reduce the rider's breathing rate so that they do not need to breath with high intensity in polluted areas. This appears to augment what the user can do and therefore it can be seen as a form of superpower. I argue that this notion of collaboration between the user and the system contributes to the research agenda of human–computer integration (Farooq & Grudin, 2017), as it taps into the partnership dynamics when working together and constructing meaning from each other's actions. Furthermore, in the cyber-physical Pedelec example, the system can draw information (pollution levels ahead) about the environment where the user will interact with the system towards supporting the experience. By gaining this knowledge inaccessible to the user's senses, the system can act on not only the user's actions but on aspects of the surroundings which can benefit or hinder the experience. This approach serves to further the design of integrated exertion, as it can offer functional applications as shown here, as well as playful applications, for example, facilitating playful applications by adjusting the assistance offered when competing with another player according to their physiological signals to even out game play. Another example is using information about the play environment to adjust the system's assistance in order to maintain a challenging pace regardless of the inclination.

In practice, designers can consider extending the user's abilities in the experience for instrumental and playful outcomes. To further enhance the partnership between the user and the system, the user should know how the system will manifest when participating in the experience, with the aims of promoting a sense of trust and collaboration, and facilitating the user momentarily letting go of 'control' in the experience for their own benefit.

Creating the framework

With the study of Ava the eBike, I was interested in exploring the sub-research question: *How do we design integrated exertion systems that can act on the user's movement data to support the user experience?*

This case study showed that facilitating an integrated exertion experience is possible by using movement data. This data was read in real time by the system as the user leaned forward and afforded the user the experience that the extra physical support came from within their body. From Ava, the first insight I learned towards creating the framework was that in integrated exertion experiences, HCI practitioners can design the system to extend the user's physical ability as Ava extends the user's physical ability to go faster. From this insight I questioned if integrated exertion systems could also extend the user's cognitive abilities around affording the user increased sense-making. The second insight from this case study towards creating the framework was that the user was in control over the extra physical support. From this I wondered if this needed to occur in all integrated exertion experiences. What would happen if the user was not always in control in relation to the user experience? And how would using other data instead of movement data work in relation to the user experience and facilitating an integration with the exerting body?

These initial findings led me to begin exploring questions that informed the first steps of the framework (Figure 17). At the end of each case study I highlight insights that led to the iteration of the framework in order to show the development process. In Chapter 7, I present the final version of the framework for designing integrated exertion experiences informed by all case studies.

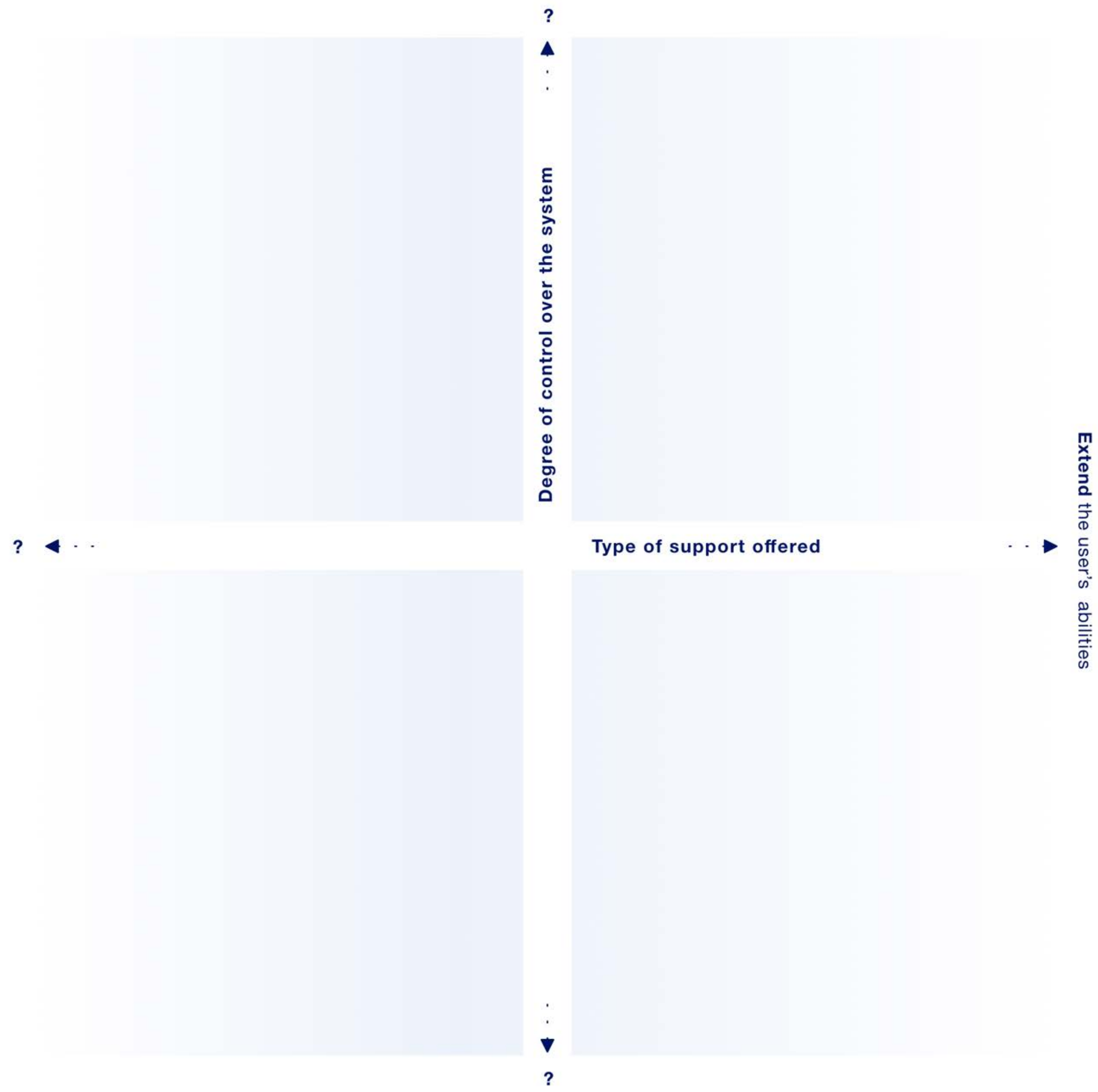


Figure 17. The first steps towards creating the framework using insights from Case Study 1.

Summary

In this case study I presented Ava the eBike, a modified eBike system that uses the user's movement data to regulate engine support when the user leans forward to embrace speed. Ava supports the user physically and resulted in design knowledge to design superpower-like experiences in integrated exertion. This knowledge was derived through a qualitative study with 22 participants using a thematic analysis approach, yielding four themes and seven design tactics to analyse and design integrated exertion experiences.

This first case study raised various questions in relation to taking the first steps towards creating the framework. This work also highlighted the potential for integrated exertion experiences to facilitate novel and enjoyable experiences. However, while with Ava the user is always in control of the system's support, the concept appeared to have room for more of the integration vision, where the system can work in a partnership with the user. As such, this suggested to me that a more advanced way of integrating with the exerting body to extend the user's abilities would be worth exploring.

In the next chapter I present Ari the eBike, which was designed to study the use of contextual data to facilitate the integration experience, rather than movement data. Furthermore, with Ari I also explored the idea of the system acting on the experience autonomously in order to support the user. Lastly, I investigated how Ari can extend the user's physical and cognitive abilities in the context of the experience in order to further my understanding of integrated exertion experiences.

CHAPTER 5

Case study 2

Integrated exertion via contextual data from around the user's body.

CHAPTER 5 – Case Study 2: Ari The eBike

In this chapter I present my second case study, Ari the eBike. In this work I explore creating an integrated exertion system that acts on the user's contextual data to support the exertion experience. Ari uses traffic light data and the user's speed to act on the experience by either increasing engine support or whispering in the rider's ear to slow down, in order to work with the rider to regulate the speed and catch traffic lights on green. This is achieved with traffic light data from traffic authorities in relation to changing traffic light patterns and by programming the speedometer and global positioning system (GPS) on a smartphone which is placed in the eBike's pannier and sends information to an Arduino. The Arduino then orchestrates either increasing engine support via the eBike's engine controller or playing the message to the rider via bone-conducting headphones. The study of Ari let me explore how an integrated exertion system can extend the user's physical abilities by offering engine support controlled by contextual data to help the user to go faster to catch traffic lights on green, as well as extending cognitive abilities by increasing sense-making that the user can benefit from to achieve the goal of catching traffic lights on green. This work resulted in themes and design tactics to analyse and create user–system co-operative integrated exertion experiences.

In this case study I explore my primary research question by investigating the sub-research question: *How do we design integrated exertion systems that can act on the user's contextual data to support the user experience?*

Table 10: Case Study 2 summary.

Publications	**Andres, J.**, Kari, T., Kaenel, J. v., & Mueller, F. (2019). **"Co-riding With My eBike to Get Green Lights"**. In Proceedings of the 2019 on Designing Interactive Systems Conference, San Diego, CA, USA. https://doi.org/10.1145/3322276.3322307
Ethics approval	CHEAN A 21422-05/18
Research question	How do we design integrated exertion systems that can act on the user's contextual data to support the user experience?
Data type	Contextual data: Traffic light data
Produced outcomes	Ari, the eBike, gives riders a new form of augmented cycling experience where the user and the system use their sensing abilities to work together to cross traffic lights on green.
Media coverage	www.technology.org/2020/01/28/never-hit-a-red-light-again-not-on-an-e-bike-at-least-video www.ibm.com/blogs/ibm-anz/meet-ari-the-smart-bike-that-helps-you-catch-green-lights www.rmit.edu.au/news/all-news/2019/oct/meet-ari-the-ebike

Ari the eBike

Ari is a novel augmented eBike designed to explore user–system co-operative exertion experiences, where the user and the system co-operate by using the information they can each sense to regulate the speed and cross all traffic lights on green. Ari takes advantage of the 'green wave' – a consecutive number of traffic lights running slightly offset – where a rider maintaining a reference speed set by the traffic authority can benefit by getting all lights on green. Ari can accelerate the engine to assist the rider physically to meet the reference speed. It can also assist the rider cognitively by whispering via bone-conducting headphones to 'slow down a little' so the rider uses the brakes to regulate the speed. Ari gives riders a new form of augmented cycling experience promoting human–bike co-operation.

System design and implementation

I have taken an incremental and exploratory approach to designing Ari, where the learnings gathered from each iteration informed the system design and implementation for the next iteration. As such, the design enquiry for Ari was carried out in four iterations, as explained below.

Iteration 1: Design considerations

I was inspired by previous augmented cycling experiences that suggest that 'design has to respect the distinctive nature of cycling as a mode of transport and needs to carefully interweave moments of interaction with it' (Rowland et al., 2009). This notion guided my thinking. I conducted a couple of sessions with the cycling community around our research lab, which has riders from varied academic backgrounds such as industrial design, computer science, sustainable transport and HCI. I drew from their expertise to discuss, sketch and derive ideas to design my system as follows:

1. Interaction in motion is difficult (Johnson & Rose, 2015; Marshall et al., 2016); as the rider is cycling and focusing on the road, interacting with a screen device can be distracting and cognitively demanding. This informed my design to avoid screen interactions and let the experience afforded by cycling be the centre of attention.

2. Communication and feedback occur regularly among users when co-operating; however, when systems do not provide regular feedback to users, this can create friction (Norman, 1990). This prompted me to consider how the system could communicate with the rider, especially as the rider needs to be aware of other riders and vehicles around them. For this reason I used bone-conducting headphones, as these allow the user’s ears to be uncovered to hear the

environment while providing the system with direct access to the user. I limited the use of sound to two instances: a) a sound described as a powerboost is played when crossing a traffic light on green to reassure the user that the system is working as expected; and b) the 'slow down a little' sound aims to offer cognitive support, facilitating the system to pass on information to the user to slow down to regulate the speed.

3. Prior work suggested fine-tuning the assistance response to be gradual yet strong in order to offer an enjoyable experience (Andres et al., 2018). This told me that I needed to experiment with the acceleration that Ari provided to riders to assist them in meeting the reference speed. I fine-tuned the acceleration over multiple trials, so the rider could experience the system increasing the acceleration gradually while allowing them to adjust, in case they needed to manoeuvre or use the brakes.

4. For safety purposes, besides recruiting experienced bike riders to minimise cycling risks, I decided that when the brakes were engaged, this would lead to a cut-off of the eBike’s engine.

These considerations informed the design of my prototype in parallel with implementation details that I describe next.

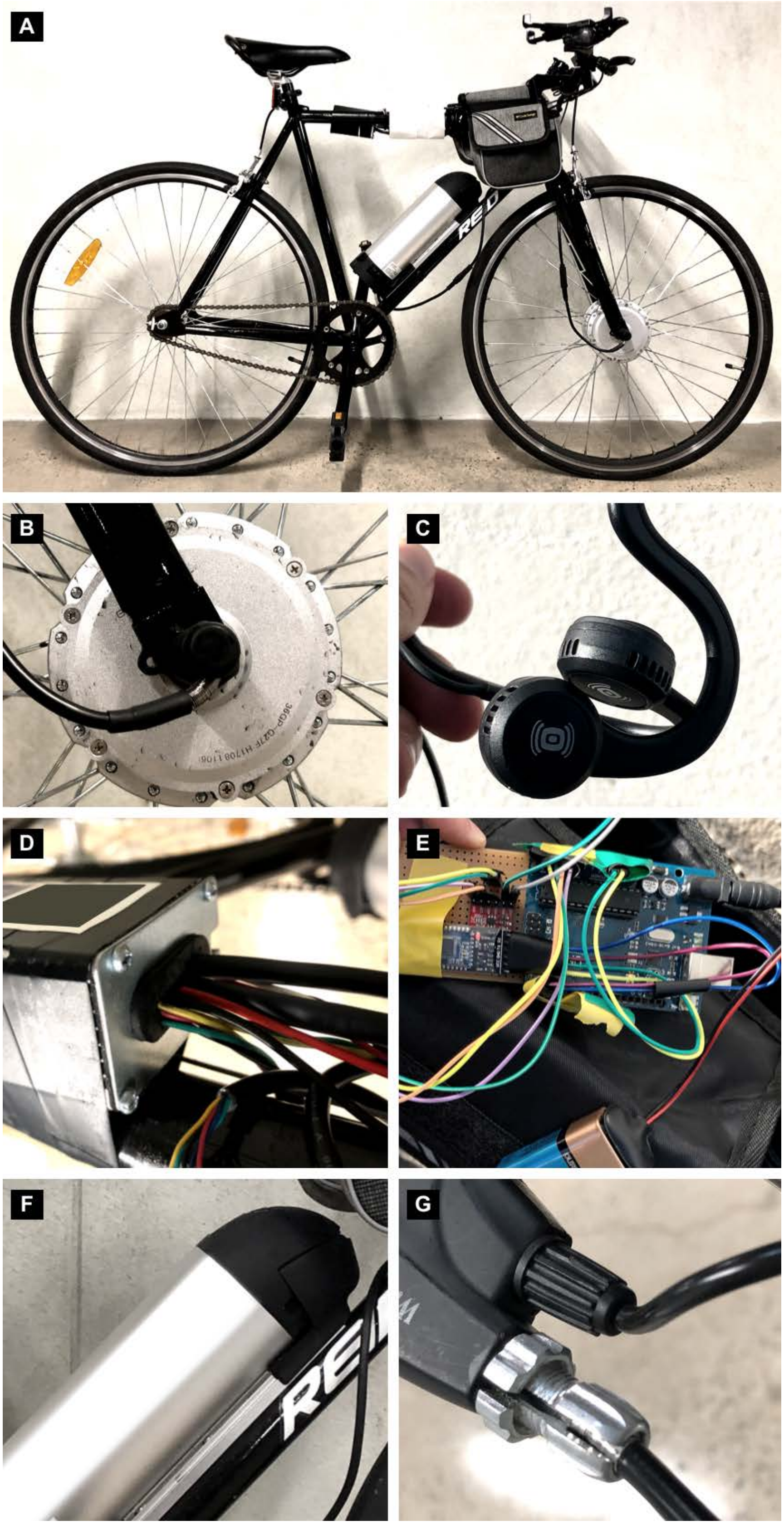


Figure 18. Ari, an augmented eBike: A) Ari's body; B) brushless motor; C) bone-conducting headphones; D) motor controller; E) Arduino Uno, F) battery; and G) brakes linked to motor controller.

System implementation

I converted a normal bike into an eBike by installing a brushless DC motor in the front wheel (Figure 18B), along with a motor controller (Figure 18D) and an 18V battery (Figure 18F).

Our approach to coordinating the engine's acceleration and the slow-down message was based on measuring the rider's speed using a smartphone's GPS, which I placed in the pannier. I built an iOS app to send the speed of the rider via Bluetooth to an Arduino Uno, to orchestrate one of the following: 1) if the rider's speed was below the reference speed, the engine should be accelerated to assist the rider to meet the reference speed; 2) if the speed of the rider was greater than the reference speed, the slow-down message was played to let the rider know to slow down; and 3) if the rider's speed was within +/−0.5km/h of the reference speed, nothing happened.

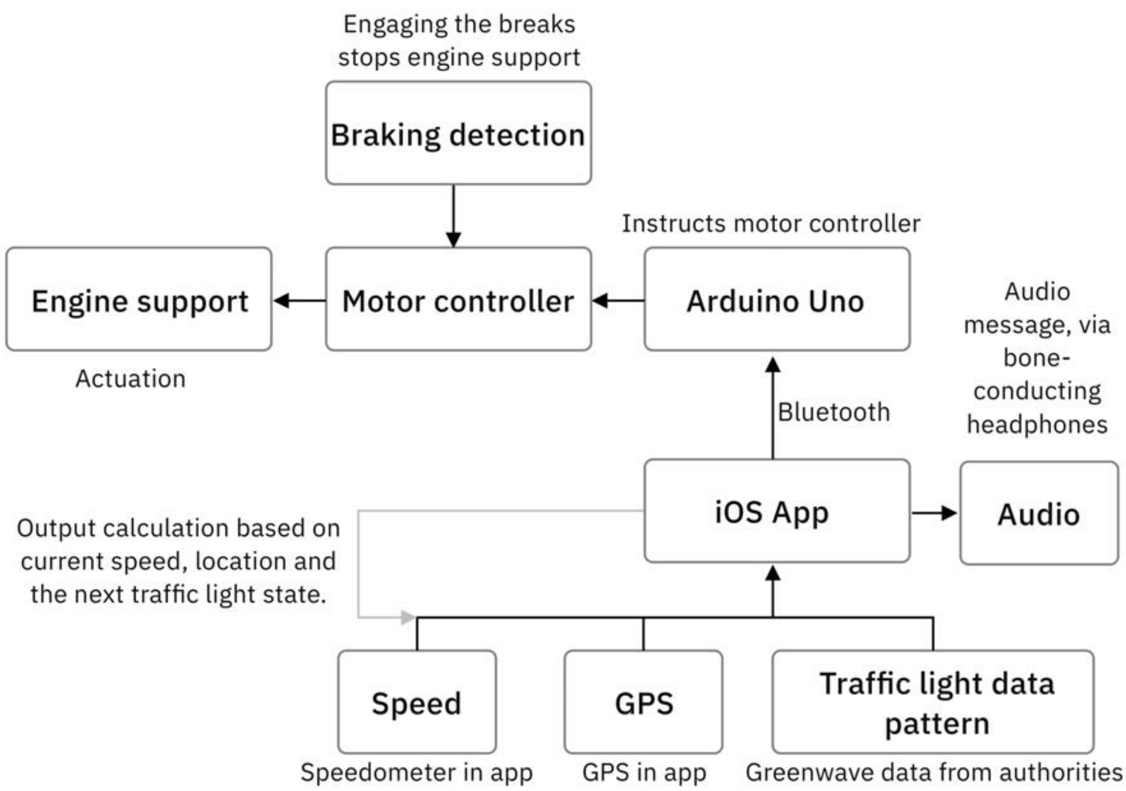


Figure 19. High level schematic of Ari's components.

Iteration 2: Studying Ari's acceleration response

I selected a park with wide bike lanes and low road inclination. In my app, I simulated the traffic lights and set a reference speed of 20km/h. I found that a speed buffer of +/−0.5km/h avoided triggering the acceleration and slow-down message too often, as illustrated in Figure 20 below. After various sessions studying Ari's acceleration response, I moved to testing on the road.

Iteration 3: Using open traffic data and moving to the road

I selected a 1km long road with three traffic lights and low inclination. The road was selected based on available traffic data from the internet. Using a reference speed of 20km/h, I had difficulty in crossing the lights on green due to the dynamic changes of the lights. At this stage I further fine-tuned the engine's acceleration to real traffic conditions.

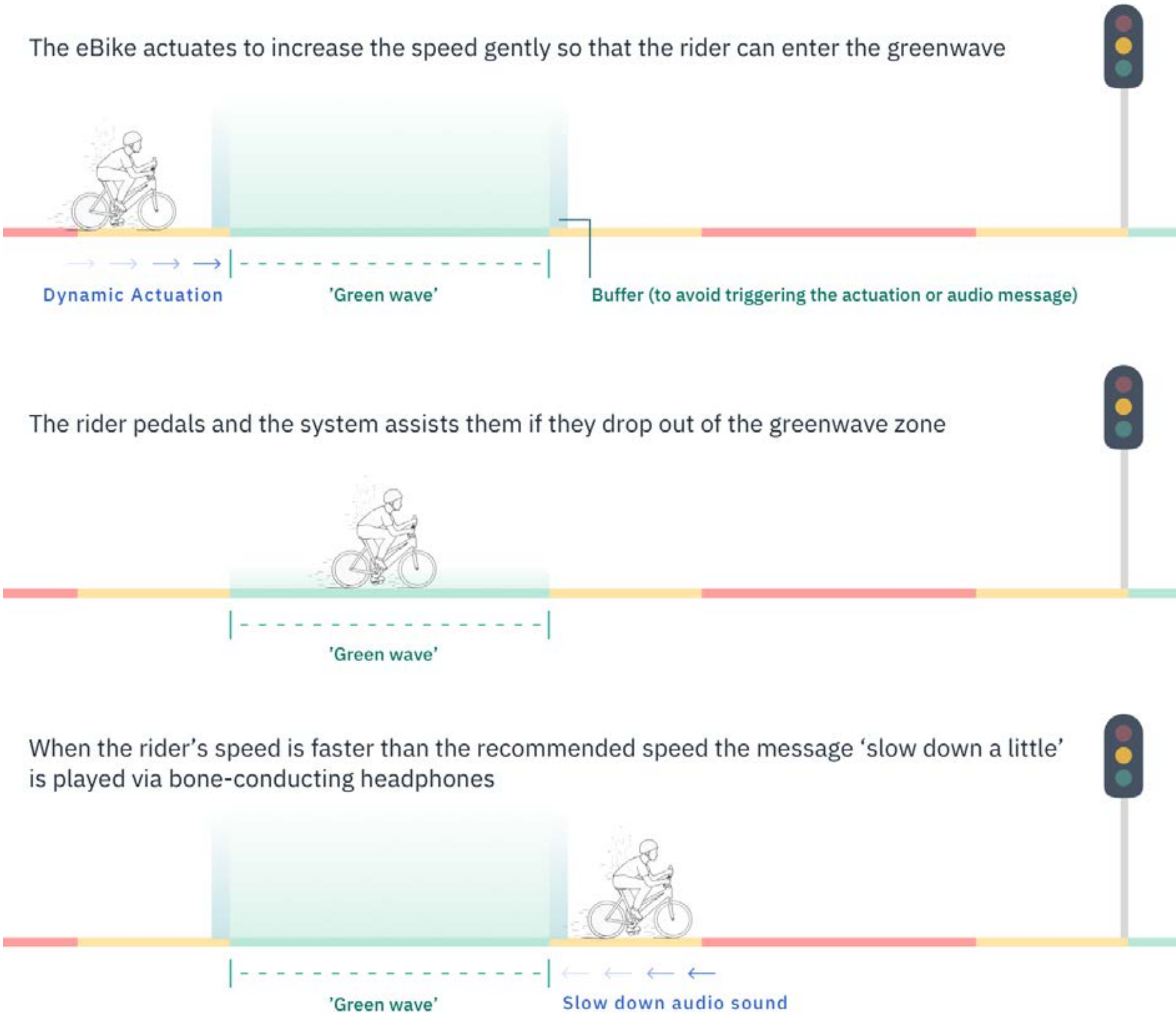


Figure 20. Ari's functionality depends on where the rider is in relation to the traffic light's current state.

Iteration 4: Working with the traffic authority

The traffic authority introduced me to SCATS, a dynamic intelligent transport system responsible for coordinating traffic light operations (Lowrie, 1990). They suggested a new location for my study as part of the green wave trial in peak hour; according to their green wave modelling, 22km/h was the reference speed the rider needed to maintain to have the greatest chance of crossing all lights on green. I received CSV files containing the traffic light cycles for each light used in the green wave and their locations. I visualised each light to identify four consecutive lights with the most consistent switching cycles to be the evaluation route (Figure 21). This allowed me to then set the reference speed, resulting in repeatable and consistent performance by my system.

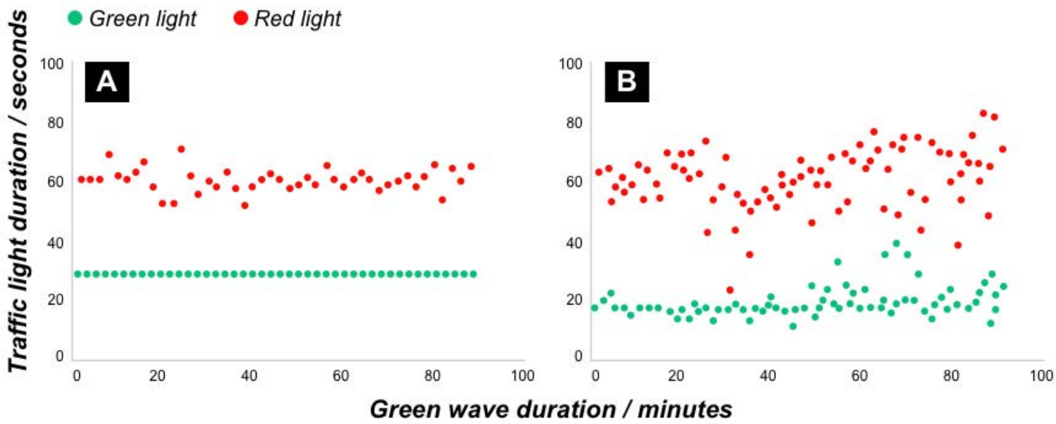


Figure 21. Visualisation of traffic light cycles, where A) shows a consistent green light duration of 30 seconds repeated over 90 minutes; and B) shows less consistent cycles not suitable for my study.

Study

I built Ari to explore systems that can co-operate with the user to augment the exertion experience. I examine the human–bike interactions in co-operating to cross all traffic lights on green. My aim was to consider what these interactions might tell me about systems that can co-operate with the user to augment the exertion experience and understand how to apply this design knowledge in theory and practice.

Participants

Ari was studied with 20 bike riders (F=6 and M=14), between the ages of 23 and 48 years (M=36 and SD=7.7), recruited via advertisement and word of mouth. My inclusion criteria were: 1) participants had to know how to cycle so that cycling risks could be minimised; and 2) they cycled at least once a week, so that they had recent cycling experiences and could compare those with Ari. Ten of the participants had previous experience with eBikes, ranging from two weeks to four years of use.

Setting

The study lasted two months and it took place in mild weather, without rain, during weekday afternoon peak times between 4:00pm and 6:00pm to ensure predictability of the traffic lights. The road used for the study was straight, offered bike lanes, had four traffic lights and was 1.2km long with 24m inclination. On average, it took participants about seven minutes to cycle from start to end.

Procedure

Participants were invited to the location and using a map on a smartphone, I showed participants the four traffic light intersections they should cycle through.

I used two eBikes, Ari and a regular pedal-assist eBike. The pedal-assist eBike, or Pedelec, is the 'default' eBike available in shops, where the user accesses the engine's assistance by pedalling. In other words, the pedal-assist eBike only accelerates the engine upon the rider pedalling hard and not by sensing or acting on information. Using these two distinct interactive systems allowed riders to contrast Ari's 'sensing and acting' against the pedal-assist eBike that required user input to offer acceleration assistance. I believe that a benefit of having two participants cycle together is that I was able to observe initial social aspects of cycling and the effect of my prototype on other riders.

The two participants, who did not know each other and were not instructed to cycle together, started cycling the 1.2km road at the same time, one using Ari and the other the pedal-assist eBike. Participants started from the low-inclination point and cycled to the end, which had the highest inclination of 24m. Once participants arrived at the end, they cycled back to the starting point; this was not part of the study and Ari was not programmed to respond. Upon returning to the starting point, participants were interviewed before I asked them to switch bikes and cycle again. In total, all participants cycled six times on the selected road, experiencing each eBike three times, resulting in an approximately 45-minute cycling experience.

Data collection

We interviewed the two participants together every time after completing the course and before switching eBikes. For the interviews, I used the explicitation approach (Obrist et al., 2013; Vermesch, 1994). This retrospective interview technique seeks first-person accounts and is often employed after an experience has happened. One of the benefits is that interviewers ask questions in relation to specific moments of the experience in a chronological order of events to learn about how the experience unfolded from the participant's perspective. This approach allowed me to capture in situ experiences including tactile details which often rapidly decay in a user's memory (Gallace & Spence, 2009; Obrist et al., 2013). As participants were interviewed every time in between switching eBikes, it appeared to allow them to be more observant when retrying Ari based on aspects that arose through interviewing; their observations were then reported on the next switch of eBikes. Every participant pair was interviewed for approximately 50 minutes.

Data analysis

I used an inductive thematic analysis (Braun & Clarke, 2006) approach to the data. Interviews were transcribed and imported into Nvivo for analysis. Two researchers independently coded and described the data. The researchers compared their codes and descriptions, and filtered them by merging clusters and discussing the data over a series of meetings. This resulted in fewer codes, which led to themes. The themes and my experiences in designing the system resulted in tactics targeted at designers who aim to design user–system co-operative integrated exertion experiences.

Results

I present the results in the form of themes with a total of 216 units coded. The results follow a chronological order of events to symbolise the user's building blocks to reach a co-operative user experience.

Theme 1: Meeting the system

This theme describes 34 units and it has two categories: *Participants' curiosity about how the system works* (7 units) and *Expectations of Ari* (27).

T1.1 Participants' curiosity about how the system works

Participants explored how the system worked by asking: 'Is this bike actually integrated with the traffic lights or is it a timetable hard coded thing?'. More analytically minded participants focused on understanding how the system worked to predict the acceleration. Participants also discussed within their pairing: 'It's not fully hard coded because it's sensing your speed in relation to the reference speed. So I would say some aspects are "real" sensing while the traffic light "speed" is fixed'.

Other participants preferred to try things on the eBike: 'I pedalled less to see if the system would feel more predictable and it did. I could understand how it works a little better', 'I pedalled fast to try and get it [Ari] to say "slow down". I understood how much faster I have to go for the sound to come up, or how slow I can go before the system picks up, to see how predictable it is'.

Once participants asked questions and tried the system, few did not like not knowing when the system was going to accelerate (6 units): 'I felt that it was speeding up and slowing down when I didn't want it to ... the light was green and it wasn't accelerating, I didn't understand why'. In this case the system did not slow down the speed, but rather stopped accelerating the engine when it was not needed. Participants reported that initially cycling with Ari was clumsy: 'I didn't do much just to see what it would do and follow, it reminded me of learning to dance'. Over time, participants became more familiar: 'It takes a ride at least to experience this type of control, you can do everything but now acceleration is not controlled by you'.

Participants utilised a mixture of questions, practical exercises and discussion to explore how the system worked and how to co-operate with it.

T1.2 Expectations of Ari

Participants' expectations ranged from seeing Ari as a prototype: 'this was a prototype and I didn't want to ruin it, I was cautious', to seeing Ari as an artificially intelligent bike, 'it's just a really cool and crazy idea to think that you're on an eBike which knows and adjusts to its environments, like an AI eBike ... it's a little bit scary but also really exciting'. Participants referred to Ari during the interviews in different ways: 'AI bike', 'smart bike' and 'cyber-horse'.

Participants wished that Ari could be aware of other cyclists (5 units): 'We caught up with a few cyclists when the bike was starting to accelerate. Even after braking a bit the bike would still try to accelerate. The bike should be aware of other cyclists because you cannot overtake them sometimes'. This relates to participants trying to understand how to co-operate with Ari in new situations. In other instances, participants reported that Ari would not allow them to reach high speeds despite the fact that they were pedalling hard (4 units): 'No matter how slow or fast you pedal, the bike knows how fast it wants to go'. Ari was not programmed to use the brakes.

After two rounds, participants discussed possible use cases for Ari: 'You want to get from A to B, you give up a bit of the control and trust the bike, and the bike just goes like, "Yes, I'm going to get you there in the most efficient way possible" ... until there's a situation in which you need a human brain to assist the bike'. This relates to participants reporting that they had to be aware of the environment to intervene when there was something that the eBike could not be aware of.

Participants also described what Ari was not good for: 'When I commute, this is perfect, a healthy way to get to work, and no one likes stopping at red lights. Obviously, that's not what you want when you're just riding a bike for leisure on the weekend because you want to enjoy going fast when you want and slowing down when you want'.

This reminded me about the balance that designers need to consider when designing interactive systems, as the borders between the user and system actions can cause friction, but also open opportunities for co-operation. Participants' expectations of the system shifted through their interactions: 'It takes a shift in your expectation of the bike but once you've made that little shift, then it's actually peaceful'.

Theme 2: Learning to co-operate with the system

This theme describes 137 units and it has four categories: *When the system acted* (35), *Users' experience of sound* (28), *Building trust with the system* (28) and *Co-operating with the system* (46).

T2.1 When the system acted

Participants reflected on Ari's actions: 'The bike started to accelerate towards a red light. If I had been cycling on my own, I wouldn't have started accelerating at that point because I didn't know that the light was going to change'.

Due to Ari's knowledge of the reference speed, at times Ari did not need to accelerate as the reference speed was being met: 'I was hoping it [Ari] would accelerate but it didn't. I was pedalling hard to get to the green light and I did, but it wasn't accelerating'. Participants shared specific details about the moments when Ari acted by accelerating the engine: 'It felt a little bit unpredictable. I didn't engage it myself, so I wasn't aware when it would stop. It was about two seconds long over 15–20 metres?'.

Participants appeared to expect to cross the traffic lights while Ari was accelerating to get the extra boost, rather than only using their input (12 units). Crossing each traffic light appeared to be seen as a finishing line where a sense of victory was elicited: 'Every light is like a separate challenge, when you cross it you move up to the next challenge' and 'When you cross the traffic light on green, it's like a victory and you become addicted to getting more green lights [laughs]'.

Participants reported the idea that Ari was taking them for a ride (7 units): 'It definitely felt like the bike was taking me as opposed to me riding the bike. It has some mystery as I don't know when it will stop accelerating, but I don't mind it since it's perfectly in sync with the lights'. Comments like these highlight the moments when Ari facilitated the rider to perceive the 'presence' of Ari and its effect on the situation: 'I see, like, a coexistence between me and the bike. I can trust it to accelerate for me, but ... in the first trial when the bike accelerated for me and I chose not to use the brakes, even if it meant putting myself in a dangerous situation because I wanted to get the green light'.

T2.2 Users' experience of sound

I mentioned to participants that sounds and messages were going to be played via the bone-conducting headphones during cycling. However, I did not specify what the sounds or messages were, with the aim of having participants explain to me what the sounds did for them during the experience. The traffic light crossing sound was received with mixed opinions, while the message to 'slow down a little' was positively received.

Participants identified the traffic light crossing sound with the system working properly: 'The bike knows where I am, that's good' and 'It's a good indication that it's working, the system is doing its thing'. Participants also associated the sound with a celebration: 'It might have been like, "congrats, you made it successfully through a green light".' Others, however, were confused about the meaning of the sound when crossing the lights: 'I didn't get it and it didn't come at a time where I felt that I needed to accelerate' and 'I don't know exactly what it was trying to tell me'. This relates to the moments where users tried to interpret what the sound meant and how this affected their experience.

In other cases the sound helped riders to experience a connection and sense of co-operation with the eBike: 'It [the sound effect] was just a novel sensation of having a different sense [hearing] of connection with the bike that you wouldn't normally use' and 'The sound gives the perception that you are collaborating with the bike when you choose to slow down after hearing the sound'.

Participants who experienced the traffic light crossing sound as a powerboost sound expected Ari to be accelerating at the same time. However, if the reference speed was being met, Ari did not need to accelerate: 'I got the powerboost sound when I made it through the green lights. I think it might have been a little out of sync with the bike's boost, you'd expect the bike to power when it plays the sound'.

In contrast, a few participants interpreted the sound as Ari telling them to accelerate by pedalling harder (3 units): 'I thought that the sound was telling me to accelerate, and since I don’t control the acceleration, I just pedalled harder'.

Participants argued against the use of the traffic light crossing sound: 'There is already joy in crossing the green lights. If you remove distractions, you may improve the act of cycling'. Participants proposed alternatives: 'The eBike could alert you before accelerating with a few bleeps'. This sound alert may aid riders by reducing the unpredictability of the eBike accelerating and could improve co-operation.

T2.3 Building trust with the system

Trust in the system was gained through repetitive actions, such as delivering on the promise of co-operating with the rider to cross the traffic lights while green. Crossing many lights while green increased participants’ trust in the system: 'I was sceptical of the bike. After crossing two lights green, I thought maybe this is actually reliable' and 'It got me through successfully the first time, so when I did the second time, I trusted it a bit more that it would do so again'.

Sound contributed to building trust, as this reassured users that the system was working with them: 'feedback provides confirmation that that's what it's meant to do. It was very clear this time that the power-up sound happened right as we passed through green lights' and 'You almost feel like you should do what the sounds are telling you, because you know that it's going to benefit you'.

Trust appeared to be weakened when the system did not meet the expectations of the user or when the system acted in a way that the user did not understand. This indicates that a degree of predictability with the system can aid in trusting the system: 'After I released the brakes the bike decided to accelerate. Maybe the bike should learn that braking multiple times means "don’t accelerate".' Ari did not have the intelligence to learn about the use of the brakes and what they could have meant from a contextual perspective. During times like these, it appeared as if Ari was challenging the authority of the rider and proceeded to work individually rather than with the rider.

There may have been a momentary negotiation of authority, when the eBike was accelerating but the rider could see obstacles ahead: 'I felt like I wanted to take the risk of putting myself in between you [the other rider] and the car passing by because I thought "oh the bike was picking up to get the green lights" so therefore I shouldn't slow it down even if that could put me in a risky situation'. Moments like this highlighted that the rider was able to identify a context that Ari did not know about – for example, understanding the road conditions, other cyclists, obstacles ahead and the proximity of other vehicles. Through practice with situations like this, the user improved their ability to co-operate with the system and this appeared to yield more trust in the system.

T2.4 Co-operating with the system

Participants explained that they experienced co-operating with the system: 'I recently started eBike riding, the traffic light bike took away the uncertainty that somebody would have about going too fast or too slow' and 'It felt like a guided bike riding, like the bike was my teacher almost'. Other participants described the exact moments when they thought they had co-operated with the eBike: 'The sweet spot was when I was like 10, 15 metres from the light and the bike kicked in, I did not have to pedal as much, we went straight through' and 'I let the eBike go and if there was car in front of us or some unexpected situation because the smart bike can't see and I can, I could take the tool back using the brakes'. Participants became more comfortable with letting the system accelerate and with actioning the slow-down message. This adjustment in cycling helped participants to become more efficient in getting the traffic lights on green by co-operating with the eBike to regulate the speed.

Furthermore, understanding the eBike's actions was important for coexistence, because as the user accumulated experience and learned to adjust to the system, the co-operation appeared to become more enjoyable: 'I felt there was coexistence because both parties did their part, it was smooth, but if the eBike was impatient, or felt the need for speed like I do sometimes, then the bike could ignore its own best intentions and put me in dangerous situations'.

More details emerged when participants were asked to describe what it was like to cycle with Ari: 'I think the traffic light bike might be co-operative. I'd say the pedal-assist augments your cycling, whereas the traffic light bike can do things that you can't and you can do things that it can't. You're sort of balancing all those skills, it's like your buddy, it knows where the traffic lights are, 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".' Another rider reported, 'The pedal-assist is kind of dumb, you pedal and it assists you and that's it. The other bike knows how to get green lights; however, you relinquish some control to the bike because it can accelerate, but you still have control of braking, left, right, stop, start'. Comments like these suggest that participants grasped the idea that adjusting to cycling with Ari allowed them to integrate their skills and facilitated co-operation.

Theme 3: Social aspects of cycling

This theme describes 9 units.

T3.1 Riders adjusted their cycling efforts to benefit from Ari

Participants described when they changed their cycling to be closer to the rider on Ari: 'I could have gone faster, but I wanted to avoid braking at the lights and having to gain momentum again, so I just followed him [the rider on Ari] to see if I could also get the lights'. Even though participants did not know each other, in some cases they followed the rider on Ari due to the augmented ability to co-operate with the rider to get green lights: 'I trusted wholeheartedly in Robert’s [the other rider] acceleration and deceleration, and followed him as close as I could. We got all the green lights together'. This shows that participants adjusted their cycling efforts to benefit from cycling along with Ari.

T3.2 Riders can be envious but also proud of co-operative cycling

Participants contrasted their experiences between the two bikes: 'He shot three or four metres in front of me before the second traffic light. I pedalled quickly to catch up with him because I thought that meant the light was changing. I felt a little annoyed because I did not know about it and he did' and 'When I cycled with the traffic light bike, it was like the eBike was my assistant and I could cycle better'.

T3.3 Giving away control leads to more careful social cycling

Participants planned how to cycle: 'We were cycling next to each other, he said, "Hey, please be careful, sometimes this bike is accelerating, it's better if you go first and I go behind".' Participants created strategies to cycle more carefully, which may have been due to Ari’s rider learning to control the acceleration provided by Ari.

Theme 4: Reminiscing moments

This theme describes 9 units.

I asked participants if cycling with Ari reminded them of other experiences, to which they said: 'When someone pushes you on a swing, you don’t know if they will keep pushing'. This relates to participants not knowing when Ari was going to accelerate. Others made comparisons with animals (6 units): 'A horse, you ride it like a bike and it can sense things that humans can't. Similarly bats or dolphins with echolocation', 'is almost like a cyber-horse, you let the bike be a horse and it goes by itself', 'Horse riding, because the acceleration kicks in without you requesting it' and 'Like a dog can smell things that you can’t, but it can alert you'. This relates to the extra sensing abilities that Ari had and how the user could gain information to regulate the speed.

I explore the similarities between human–animal and human–system co-operation under design tactics.

Theme 5: Participants’ suggestions

This theme describes 27 units.

Participants made suggestions about the moments when Ari was about to accelerate: 'There was voice guidance to tell me to slow down but I did not know when the bike was going to accelerate. I’d expect voice guidance to announce the acceleration too'. Voice announcement may aid the user to learn faster to co-operate with Ari and it could contribute to lower uncertainty. Furthermore, voices or sounds, or engaging other senses to deliver information, could facilitate opportunities to improve co-operation.

Other suggestions focused on gaining knowledge about the traffic lights through Ari so that the rider could predict what was about to happen: 'If it gave you a sound warning when the light is going to change few seconds before, "Hoot. Hoot. Hoot."' and 'A countdown to green because then maybe I could speed off on my own and I wouldn't need the assistance'.

Participants suggested that the eBike could provide a data log showing how the rider and the eBike regulated the speed (6 units): 'With any kind of intelligent system it takes time for humans to build up trust. If after a trip it showed the data of how it did it, you could look and be like, "I sped up here and then maybe just made the traffic light", this may be reassuring'. Others wished for additional information during cycling: 'Maybe additional traffic info about upcoming roads in your path, via the headphones'.

Suggestions in relation to conversing with Ari were also discussed (3 units), 'If it could tell you in some way that it's about to do something, or if you could tell the eBike about other riders and not to accelerate'. This suggestion may be useful to further co-operating with the system.

Design tactics

I present six design tactics that emerged from the study results.

Tactic 1: Contextual cues to facilitate skill integration

Derived from themes: *Expectations of Ari (T1), Users' experience of sound, Co-operating with the system (T2) and Social aspects of cycling (T3).*

Skill integration is the premise for co-operation; according to Doran et al. (1997), co-operation happens when the actions of each user/system satisfy either or both of the following:

- The user and the system have a goal in common
- The user and the system perform actions to enable or achieve not only their own goals, but also the goals of others.

To achieve the common goals, the user and the system pass on information to each other based on the sensing abilities they have. In the case of Ari, the user and the system could sense and act on different information during cycling, which allowed them together to regulate the speed to cross all traffic lights on green. Contextual cues such as 'slow down a little' facilitated passing on information from the system to the user, who then executed this instruction by slowing down, resulting in skill integration.

To facilitate skill integration, I suggest:

- The user should understand the benefit of co-operating; this will assist them in considering and valuing co-operating.
- The system should use brief contextual cues that the user can easily action; this would reduce operational complexity for ad hoc execution.
- The system should adapt its contribution according to the user's efforts; this would allow the user to grasp the dynamics of the co-operation and adjust their own contribution.
- There should be a bilateral relation when it comes to shaping each other (the user and the system) through interaction to improve co-operation – rather than, say, only a unilateral relation where either the user or the system adjusts to the other. This would allow the user and the system to co-operate more effectively through practice.

Tactic 2: Contextual meaning to craft system response

Derived from themes: *Expectations of Ari (T1), Users' experience of sound, When the system acted (T2) and Social aspects of cycling (T3).*

Users often perceived each traffic light as a finishing line and expected the traffic light's crossing sound to be accompanied by Ari's acceleration while crossing. Ari was not designed to always accelerate while crossing traffic lights, as its acceleration was determined by meeting the reference speed.

Designers could enquire about the users' contextual meaning of the environment, such as perceiving the traffic lights as finishing lines, with the aim of crafting the system's response. This could offer designers ideas to craft the the system response to the environment from the user's contextual meaning, resulting in experiences that fulfil or challenge the user's expectations.

Another example relates to the system not being aware of other cyclists and the rider pressing the brakes multiple times to stop the acceleration. Capturing such occurrences can allow designers to craft the system to respond according to the situation and it may also offer opportunities to customise the system to a particular user's interaction. This customisation could build on the idea that through interaction, the user and the system shape each other to attain better co-operation (Wuertz et al., 2018).

Tactic 3: Drawing from human–animal co-operation to inform human–system co-operation

Derived from themes: *Building trust with the system (T2) and Reminiscing moments (T4).*

Participants drew comparisons between animals and Ari due to the complementation of skills: the rider was responsible for pedalling, navigating and manoeuvring, while Ari was responsible for monitoring the speed, accelerating the engine and informing the rider if they were going too fast. Humans and animals have co-operated previously (e.g. guide dogs (Naderi et al., 2001), dog–shepherd co-operation (Keil, 2015) and rider–horse co-operation (Hausberger et al., 2008)). In this tactic, designers can consider the similarities between human–animal and human–system co-operation for future designs as shown in Table11.

Table 11: Similarities in human–animal and human–system co-operation.

User actions	Coop. animal	Coop. system
Feeding	x	Via the battery
Cleaning	x	General maintenance
Keep up with vaccinations	x	Maintain software updates for security/ functionality
Analyse excrement to learn about its wellbeing/ performance	x	Analyse the system's activity log to learn about its performance
Adjustment over repeated use for better coop.	It learns through practice	It can be designed to adjust to the user's repeated interactions
I seek to trust the animal to build coop.	It develops a bond with the owner	It can be designed to gain the user's trust (Tactic 4)
Rewards/punishes for training	It is receptive and learns from the owner	It can be designed with a reward/ punishment feedback loop
It has emotions (e.g. impatience) and personality	It has emotions and personality	It can be designed to showcase emotions and personality
There is hierarchy, the leader can gain control through commands	It often responds to the leader via commands	It can be designed to show different levels of obedience (Tactic 6)

The animal co-operation literature has focused on questions such as: 'When to co-operate?, 'With whom to co-operate?', 'What to do in co-operative interactions?' and 'How much to contribute to co-operation?' (McAuliffe & Thornton, 2015). I believe designers of co-operative systems can also ask these questions to explore user-system co-operation in relation to the experience.

Tactic 4: Making co-operative systems more trustworthy

Derived from themes: *Expectations of Ari (T1), Users' experience of sound, Building trust with the system (T2) and Co-operating with the system (T2).*

Trust is a large challenge when systems can co-operate with the user during the experience due to the fact that trust facilitates acceptance and can also define how users interact with technology (Siau & Wang, 2018). By design, co-operative systems could 'communicate' with the user to gain their trust; communication enhances co-operation (Wuertz et al., 2018) because it links meaning and action (Donnellon et al., 1986), facilitating user–system co-operation.

Ari used two sounds to communicate. The traffic light crossing sound was intended to reassure the user that the system was working; however, this sound was abstract and led to multiple interpretations. Over time, it became a burden, as the user knew the system was working. I suggest fading out reassurance communications if the user can perceive the system is performing as expected. As co-operation improves, designers should aim for uninterrupted co-operation.

The second sound, 'slow down a little', was derived from the system sensing the speed to determine if the user needed to slow down to meet the reference speed. Once the system identified that the user was going faster than the reference speed, it generated the message to facilitate the link between meaning and the user then actioning this, to slow down, facilitating co-operation.

For complex operations I suggest using brief voice messages as meaningful actionable instructions during the experience. Less complex actions could focus on using abstract sounds or even haptics after the user has learned the meaning of such communications. Text as a form of communication could be used in a post-activity log to facilitate reflection on how the co-operation unfolded. This can provide the user with insights into the system's performance and promote trust in future operations.

Conversational abilities were suggested for Ari. Here designers can draw from the large body of research on conversational agents and personality (e.g. (Cowell & Stanney, 2003; Michael, 2016; Serban et al., 2016)). For this approach I suggest making conversations brief and instructional during the activity to pass on actionable insights that benefit the experience.

Tactic 5: Making co-operative systems inclusive

Derived from themes: *Expectations of Ari (T1) and Participants' suggestions (T5).*

By design, co-operative systems can be more inclusive than systems that depend on user input, because co-operative systems can 'sense and act' to compensate the user's efforts in relation to joint operations. As an example, consider the co-operation between service animals and the visually impaired: as the user's vision deteriorates over time, the service animal will take on more responsibilities due to the fact that it can 'sense and act' to adjust to the co-operation. Similarly, co-operative systems can adjust their contribution according to the user's abilities improving or deteriorating over time.

As proposed in Tactic 4, making co-operative systems more trustworthy can result in making the experience more inclusive. The system can be informative and complementary to the user's awareness (Abascal & Nicolle, 2005) and it can also adjust its language and choose a suitable user sense to engage with (e.g. instead of voice messages for users without hearing, explore haptics as an alternative (Jayant et al., 2010)). Co-operative systems can facilitate less able users to participate in social situations not previously possible, due to the system complementing the user's physical and cognitive abilities in relation to the activity. One such example is group cycling; the system could complement a rider's physical efforts to keep up with the cycling group.

Tactic 6: Influencing the user's perception of control over the co-operative system

Derived from themes: *Participant's curiosity about how the system works, Expectations of Ari (T1), When the system acted and Users' experience of sound (T2).*

Users' perceived level of control over Ari varied for multiple reasons, such as trust in the system, how comfortable they felt cycling and how much experience they had. This tactic shows how the perceived level of control over the co-operative system can result in different user experiences that designers can consider when crafting co-operative systems as shown in Table 12.

Table 12: User's perception of control over the co-operative system and the resulting user experience.

User's perception of control over the co-operative system		
Low	**Medium**	**High**
Situational examples from my study		
The user is sceptical of the system. Their trust in the system is diminished through experiences that do not meet their expectations.	The user regularly tests the system to explore its response and predictability – they are finding a middle ground to improve co-operation.	The user adjusts to co-operating with the system: they understand the tasks they are responsible for. They let the system go as they know that they can regain control.
Resulting user experience terms and key quotes		
Conflicting user experience; The user has difficulty letting go of control, they do not enjoy the system's actions and try to overwrite them. 'I did not understand why it was slowing down, it was unpredictable'.	Fiddly user experience; The user fiddles with the system seeking an explanation for the system's actions – back and forth in a clumsy experience. 'I pedalled less to understand it, it reminded me of learning to dance'.	Co-operative user experience; The user perceives they are in control and leverages the system for their benefit, they understand that co-operating increases their skills. 'I cycle better, more effectively, you're sort of balancing all those skills, it's like your buddy'.

I see that the user's perception of control over the co-operative system is transitional – progressing over time from low to high. This tactic aids designers by highlighting things to look out for using the *situational examples* and *resulting user experiences.* Designers can then leverage the presented tactics to iterate their design in order to assist users in reaching the co-operative stage.

Reflections

I did not collect data on acceleration usage as the engine support was triggered automatically when the rider was going below the target speed to get to the next traffic light on green. The rider also did not have access to a mechanism to trigger extra engine support. An interesting configuration of this work could compare if eBike riders that can engage engine support themselves as well as having the system increase engine support automatically in relation to the speed, location and the traffic light patterns can catch more lights in green that those where the user does not have access to trigger the extra engine support and only the system can increase engine support automatically.

Creating the framework

With the study of Ari the eBike, I was interested in exploring the sub-research question: *How do we design integrated exertion systems that can act on the user's contextual data to support the user experience?*

This case study showed that facilitating an integrated exertion experience was possible by using contextual data. Using contextual data resulted in a very different experience to Case Study 1, as the system could act on the experience autonomously. In my case this meant that the integrated exertion systems could be designed to support the user's goal of catching traffic lights on green. Furthermore, this study showed that integrated exertion systems can offer the user increased sense-making ability as well as physical support. From Ari, the first insight I learned towards iterating the framework is that in integrated exertion experiences HCI practitioners can design the system to extend the user's physical, as well as cognitive, ability in the form of increased sense-making, as Ari offers instrumental information via the whisper to the rider to regulate their speed. From this insight I questioned if integrated exertion systems could extend the user's cognitive abilities to afford increased perceptual awareness, such as the user being aware of their own physiological data, which is often invisible. Furthermore, would using another data type such as physiological data be possible to allow an integrated exertion experience and what kind of experience could it afford to the user?

The second insight from this case study towards iterating the framework was that the user in Case Study 1 was in control of the system's support and in Case Study 2 the user had little control over the system's support. From this insight I wondered if using another data type could result in a middle point where the user had some control over the system's support? Thirdly, comparing Case Studies 1 and 2, it appears that in Case Study 1 the system acted on the experience simultaneously as the user leaned forward, in a synchronous manner. In Case Study 2, the system acted on in the experience much like a teammate who wants to co-operate to achieve a common goal independently from the user.

These findings offered some answers for the first case study and pointed to iterations of the 'control' axis of the framework, showing that in integrated exertion experiences the user's control over the system can vary and this can result in a different user experience (Figure 22). Moreover, these case studies facilitated reflection around vocabulary to define the types of experiences that integrated exertion can offer (co-operative, synchronous and instrumental). This led me to consider if there were states in between these types.

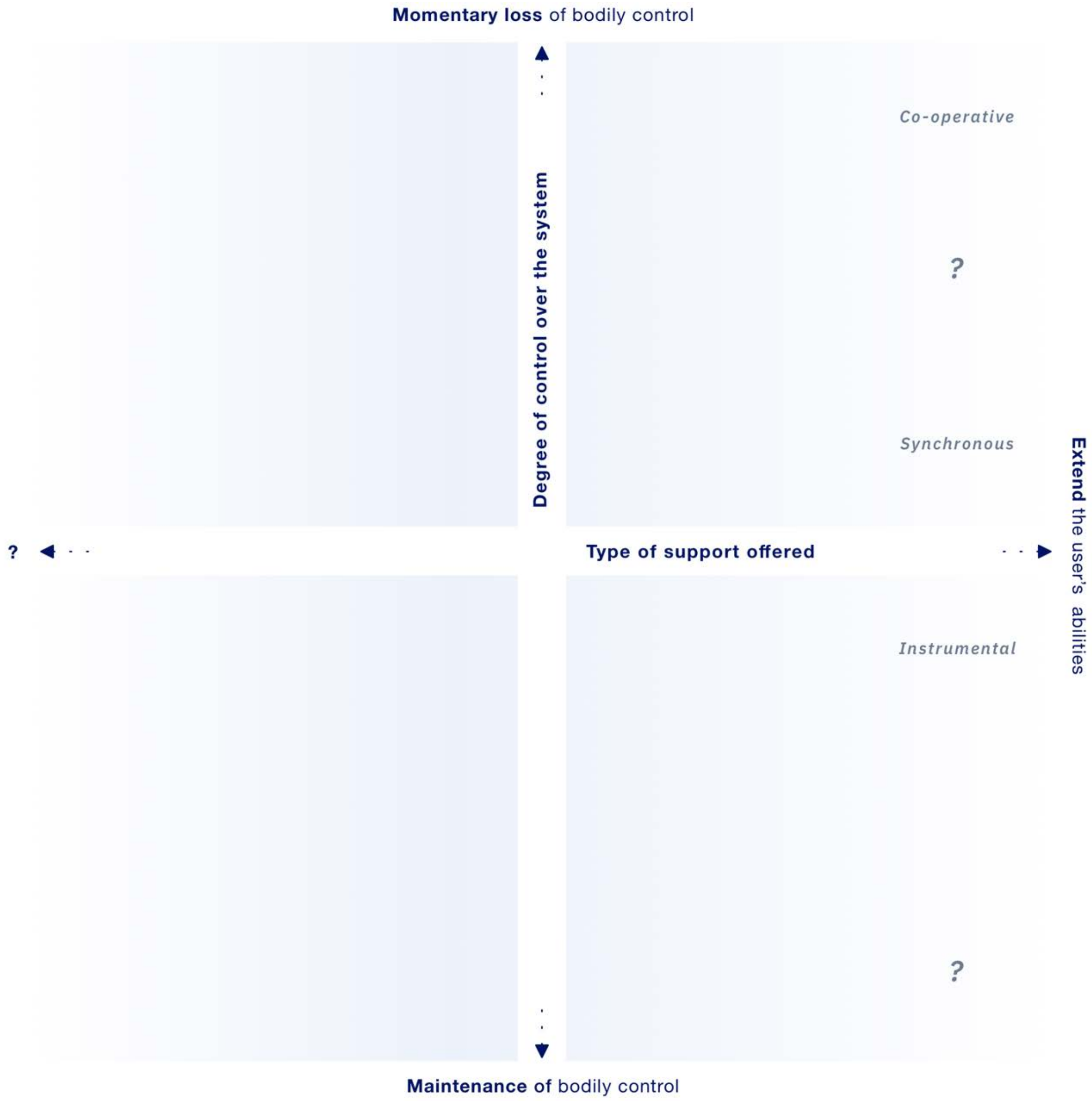


Figure 22. The second iteration towards creating the framework using insights from Case Studies 1 and 2.

Summary

In this case study I presented Ari the eBike, a modified eBike system that uses contextual data to regulate engine support to physically support the user to go faster and whispers in the rider's ear in order to support the user cognitively by affording increased sense-making to regulate their speed and catch traffic lights on green. Ari extended the user's physical and cognitive abilities, and resulted in design knowledge to inform user–system co-operative-like experiences in integrated exertion. This knowledge was derived through a qualitative study with 20 participants using a thematic analysis approach, yielding five themes and six design tactics to analyse and design integrated exertion experiences.

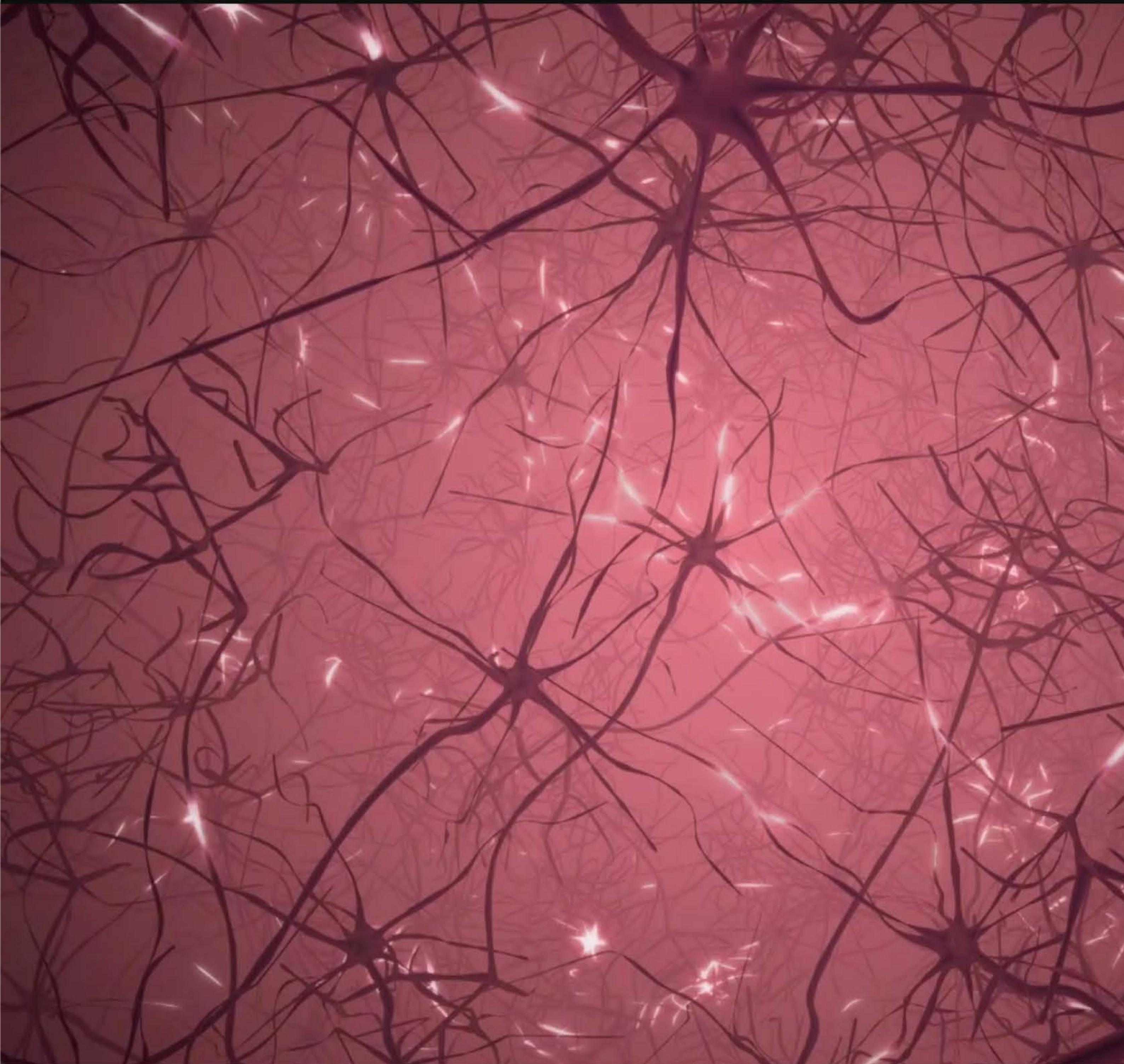
This second case study showed that different data can result in different integrated exertion experiences, especially since this data can inform when and how the system acts on the experience. This is something that differs from Case Study 1 where the data corresponded to the user's movement and, as such, the user was always in control. This work highlighted the potential for integrated exertion experiences to facilitate user–system co-operative experiences by using contextual data. However, it led me to consider that in the first case study I focused on movement data from the user's body, and in the second case study I focused on contextual data from around the user's body. Therefore, a sequential next step was to explore integrated exertion by focusing on physiological data from inside the user's body in order to further discover the design space that integrated exertion offers.

In the next chapter I present Ena the eBike, which was designed to study the use of physiological data to facilitate an integrated exertion experience. With Ena, I explored how the system can access the user's neurological activity in relation to changes in their field of view to regulate engine support. This in turn could facilitate users to experience kinetic feedback via increased engine support to go faster when the user reached peripheral awareness, thus extending the user's cognitive ability by gaining increased perception of their peripheral awareness and also extending the user's physical ability to cycle more effortlessly.

CHAPTER 6

Case study 3

Integrated exertion via physiological data from inside the user's body.



CHAPTER 6 – Case Study 3: Ena The eBike

In this chapter I present my third case study, Ena the eBike. In this work I explore creating an integrated exertion system that acts on the user's physiological data to support the exertion experience. Ena uses an electroencephalogram (EEG) cap to monitor neurological activity in relation to the user's field of view, indicative of the rider reaching a state of peripheral awareness, to regulate engine support. This is achieved with physiological data corresponding to the rider's neurological activity read using an EEG cap connected to an OpenBCI Cyton board and OpenBCI GUI. When this data is between 0.76μV–1.19μV within the high alpha range of 10–12Hz, it corresponds to the rider being in a state of peripheral awareness. The OpenBCI GUI is connected to an Arduino which signals to the eBike's engine controller when to activate or stop engine support. The study of Ena let me explore how an integrated exertion system can extend the user's physical and cognitive abilities by offering engine support controlled by the user accessing their peripheral awareness and resulting in a kinetic feedback loop that offers increased perception to the rider around their own physiological data. This work resulted in themes and design tactics to analyse and create user–system symbiotic-like experiences in integrated exertion.

In this case study I explore my primary research question by investigating the sub-research question: *How do we design integrated exertion systems that can act on the user's physiological data to support the user experience?*

Table 13: Case Study 3 summary.

Publications	**Andres**, J., Schraefel, M., Semertzidis, N., Dwivedi, B., Kulwe, Y., von Kaenel, J., & Mueller, F. (2020, April). **Using Peripheral Awareness as a Neurological State for Integrated Exertion**. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM. https://doi.org/10.1145/3313831.3376128
Ethics approval	CHEAN A&B 22071-03&04/19
Research question	How do we design integrated exertion systems that can act on to the user's physiological data to support the user experience?
Data type	Physiological data: EEG to monitor changes in the user's field of view
Produced outcomes	Ena the eBike regulates its engine support by monitoring in real time changes to the user's field of view relating to whether the user is in a state of peripheral awareness or not via electroencephalogram (EEG), resulting in a symbiotic-like integration experience where Ena can access a user's pre-attentive processing state to regulate engine support.

Ena the eBike

Ena the eBike is a novel modified eBike connected to the EEG signals of the rider via an Ag/AgCl coated electrode cap. Continuous physical support is offered to the rider by the eBike's electrical engine when the EEG signals of the rider are between 0.76μV–1.19μV within the high alpha range of 10–12Hz. These figures correspond to the rider being in a state of peripheral awareness, which is known to facilitate better athletic performance, coordination and awareness of the environment (Lemmink et al., 2005; Nan et al., 2014; Nan et al., 2013).

The eBike

I converted a regular bike into an eBike by installing a brushless DC engine in the front wheel, an 18V battery on the eBike's body and an engine controller linked to an Arduino that can receive signals corresponding to the processed EEG to control the engine acceleration support.

The EEG system

To connect the participant's neural electrophysiological signal with Ena, I used an EEG system comprised of an OpenBCI Cyton (BCI, 2019a) and an Ag/AgCl coated electrode cap (BCI, 2019b), using the 10/20 electrode placement. Electrodes O1 and O2, with AFz as ground and CPz as reference stream data, and electroconductive paste was used to improve contact between the participant's scalp and the electrodes (Figure 23, 24). This electrode montage was validated by previous studies assessing peripheral awareness (Figure 25) via EEG (Lemmink et al., 2005; Nan et al., 2014; Nan et al., 2013).

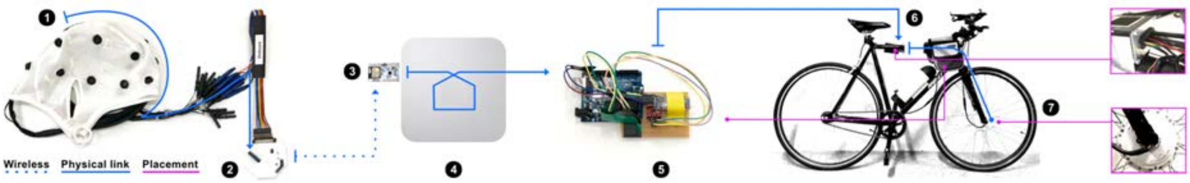


Figure 23. Changes in peripheral awareness in real time regulate the eBike's engine: 1) Ag/AgCl coated electrode cap; 2) Cyton board for EEG reading; 3) Bluetooth receiver; 4) Mac running OpenBCI for EEG classification; 5) Arduino converting Boolean to Integer corresponding to whether the rider is peripherally aware or not; 6) eBike's engine controller to regulate engine support; 7) eBike's engine.

Figure 24. Ena in action (left). Data is streamed via electrodes O1 and O2 (top), with AFz as ground and CPz as reference (bottom).

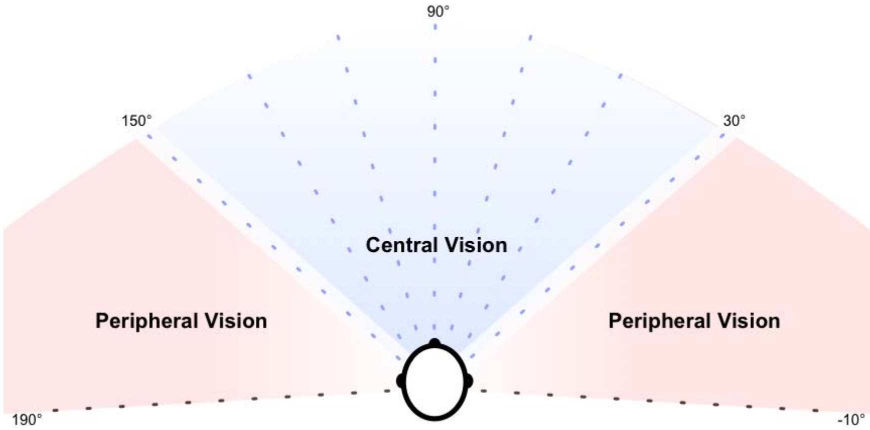


Figure 25. Illustration of central vision and peripheral vision.

Deriving a peripherally aware state from EEG data

Using EEG to derive a mental state from a user in a mobile setting is challenging due to the vast amount of raw EEG data generated and the noise resulting from the user's movements (Lau-Zhu et al. 2019). To compensate for this challenge I took the following measures: First, from the hardware side, I first 3D printed three sizes of Ag/AgCl coated electrode caps so that the fitting on the user's head was as flush as possible so that it did not contribute to further noise in the signal. Secondly, from the software implementation side, the target values for determining peripheral awareness were established by taking the mean voltage values exhibited by individuals in a state of peripheral awareness from previous studies conducted by Nan et al. (2014, 2013). However, it is acknowledged that EEG sensing in mobile settings is still far from perfect and will hopefully improve in the future with better sensors and other technical advances.

The EEG raw data was collected from the participant's scalp at a sampling rate of 250Hz and streamed via Bluetooth to a small laptop placed in the eBike's pannier for signal processing using OpenBCI (2019). Fast Fourier transforms (FFT) at a rate of 1024/s were applied to the raw EEG data to translate the signal into the frequency domain. Furthermore, a bandpass filter of 7–13Hz was applied to the EEG stream to single out frequencies which have been demonstrated to be associated with peripheral awareness in the context of the electrode montage I have adopted. To assess the participant's engagement in peripheral awareness, the calculations were performed in real time while the participant was riding Ena. When a participant's values fell between 0.76μV–1.19μV within the high alpha range of 10–12Hz and 0μV–0.7μV within the beta range of 12–13Hz, the software inferred that the participant was in a peripherally aware state. Values falling outside these parameters indicated that the participant was not peripherally aware (Figure 26). The addition of beta was used in reference to alpha to ensure signals that reached the desired alpha pattern were not a product of noise across all bandwidths. This was further complemented by the use of a mean smoothing filter to mitigate movement artefacts (Azami, Mohammadi, & Bozorgtabar, 2012). Lastly, the values were used to calculate an output Boolean of 'true' when participants were peripherally aware and 'false' when participants were not.

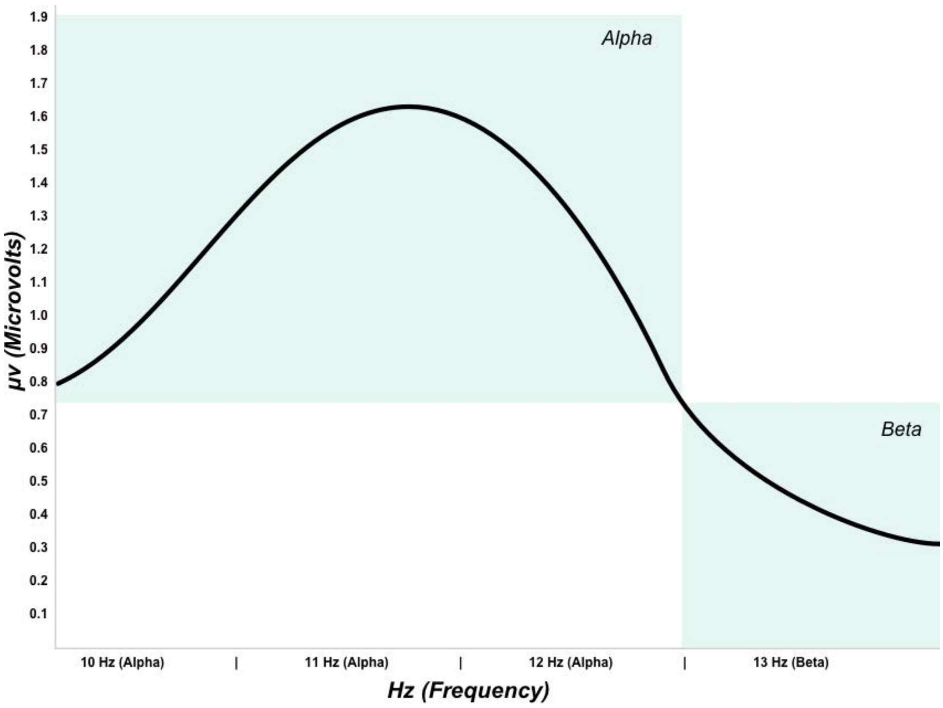


Figure 26. If the FFT above is in both the green zones, it suggests that the user is in a peripherally aware state.

Regulating the eBike's engine support

The output Boolean was then sent to the Arduino board over a wired serial connection at a baud rate of 56,700 bits/s. The Arduino interfaced with the eBike's engine via a digital-to-analogue converter. Once the Arduino found the Boolean to be 'true', it output a command to activate engine support; when the Boolean was 'false', it output a command to terminate engine support (if it was applied). Figure 27 below shows all components of the system.

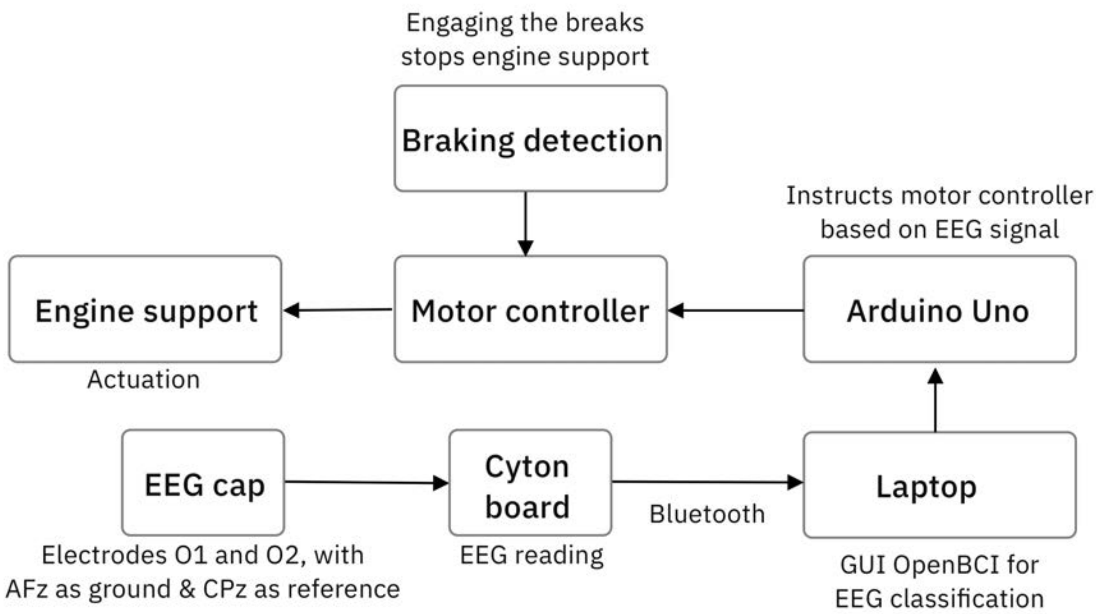


Figure 27. High level schematic of Ena's components.

Safety considerations

To lower potential risks, I took the following measures: 1) when the user engaged the brakes, the eBike's engine was cut off regardless of EEG state; 2) Ena offered engine support gradually, as an aggressive increase could be perceived by the rider as a threat and affect their field of view by narrowing it; and 3) I only recruited experienced bike riders.

Study

I built Ena to study peripheral awareness as a neurological state for human–computer integration in an exertion context.

Participants

Ena was studied with 20 bike riders (F=8 and M=12), between the ages of 24 and 58 years (M=39.8 and SD=10.5), recruited via advertisement and word of mouth. My inclusion criteria were: 1) participants had to know how to cycle so that cycling risk could be reduced; and 2) they cycled a minimum of once a week, so that they had recent cycling experiences to compare with their experiences using my system. Seven participants had previous experience cycling eBikes, ranging from two weeks to four years.

Setting

The study lasted three months and it took place in mild weather, without rain, in the afternoon on a suburban street. The road used was straight, flat, about 1.5 kilometres in length and it did not have traffic lights. I selected this road as riders could cycle continuously without stopping and it often had bikes, pedestrians and vehicles to offer a realistic setting. It took participants approximately seven minutes to cycle from the start to the end and return to the starting point.

Procedure

Each participant was invited individually to the location to receive a briefing about the study and safety procedures.

Study setup: Peripheral training and feedback

I started with a sports science video exercise that guided the participant to practise reaching peripheral awareness (Cobb, 2014). The video invited the participant to stand up straight, fix their gaze on a point in the distance and breathe in and out slowly a few times to relax (extending their arms to the sides and bending their hands forward to move their fingers until their peripheral view caught on to the finger movement). Participants gradually adjusted how extended their arms were to test their peripheral vision, detecting the finger movement while their gaze remained fixed in front. This was followed by the researchers placing the Ag/AgCl coated electrode cap on the participant and connecting the system. The participant then cycled the course twice while trying to access their peripheral awareness. Upon returning to the starting point, I asked participants if they had experienced the system increasing engine support and I also reviewed the collected EEG data to see if, and for how long, they had reached peripheral awareness. When a participant did not reach peripheral awareness, I invited them to watch the video again and practise cycling a few times. All the participants were able to reach peripheral awareness for different duration while cycling before proceeding with the study.

Study procedure

After the study was set up, which included adjusting the system for comfort, the participant proceeded to cycle the course a minimum of six laps, as this would offer approximately 40 minutes of total cycling time. In between laps, I conducted five 10-minute interviews.

Data collection

I collected EEG data from all participants that showed when and for how long they had reached peripheral awareness, and this data was accessible to the participants during interviews. Each participant was interviewed every time they returned to the starting point, with each interview lasting approximately 10 minutes, resulting in each participant being interviewed for approximately 50 minutes in total. To draw from the participants' experience I used the explicitation approach (Obrist et al., 2013; Vermesch, 1994) to capture first-person in situ observations. I chose this approach as it provided participants with a way to tell me 'what happened' throughout key moments of the experience in great detail from their perspective.

Data analysis

I used an inductive thematic analysis approach to the data (Braun & Clarke, 2006). Two of the authors individually coded the interview transcripts using Nvivo software, and over several meetings discussed them and converged them into themes. The themes, including the participants' quotes and my experience in designing the system, served as the foundation to develop design tactics phrased as practical takeaways (Blandford, 2013).

Results

I present the results in the form of themes with a total of 292 units coded. The results are organised to reflect how the user experience unfolded.

Theme 1: Participants' user experience highlights

This theme describes 51 units and it has three sub-themes.

T1.1: The system is integrated with my brain and it can act on before I do (24 units)

Participants shared their reflections in relation to interacting with the system; for example, 'It is directly from my brain wave, there's no need to think about what kind of function I need to do or how to raise attention to pass information'. It was particularly interesting to hear about participants' experiences when navigating the environment and encountering obstacles. One participant said: 'There's a minor moment of panic where you realise, "Hey, I need to quickly find a way to avoid this incoming thing [referring to other bikes, pedestrians or vehicles that may obstruct the way if they continue ahead]". That is when the bike slows down and it gives you time to think' and 'The bike is actually responding before I'm capable, that's really powerful'. In occurrences like these, the system responded to the situation by stopping the engine support before the rider could reach the brakes, resulting in the eBike slowing. This occurred as the rider perceived the oncoming obstacle as 'the threat', narrowing down their field of view and resulting in EEG signal changes that terminated the eBike’s engine support.

T1.2: The world became a video game (9 units)

Participants engaged with other riders and pedestrians to negotiate and navigate the environment. One participant stated: 'I felt like I was participating in the environment to negotiate where I was going. This clarity of knowing where I was going triggered the acceleration and it made it feel like a game'. This appears to have resulted from riders finding out that once they had no oncoming obstacles and a way in mind to go ahead, the system’s engine support could be triggered. When the rider looked away to focus on a potential obstacle, such as another bike or pedestrian passing by, this resulted in changes to the EEG signal and therefore the system stopped offering engine support. One participant 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'.

T1.3: The experience can be elating, dramatic and surreal (18 units)

Participants described a variety of emotions in relation to their experience. One participant stated: 'You get a mini high when it starts going' and 'You feel like a kid again'. In another case, a participant reached out after the session to tell us: 'I just felt that same feeling I had today when the bike pushed me ... when you drive for hours and your feet still feel the vibration from the accelerator, this shared control of the acceleration makes it a rather dramatic experience'. This echoed the experience that other participants (7 units) also had in relation to trying to master controlling the engine support but were unable to do so immediately. Lastly, participants (5 units) commented about how they needed to be in sync with their inner body to get the system to provide engine support. One participant said: 'It feels a bit surreal because you need to be in sync with your body to get the bike to accelerate, and it then stops accelerating before I realise that is what I wanted to do', 'it accelerates more when I'm more relaxed' and 'if you are uncertain and you start to look around, the bike would not go'.

Theme 2: The user experience of peripheral awareness as a mechanism for integration

This theme describes 88 units and has four sub-themes.

T2.1: The system responded to how I was seeing the world (9 units)

Participants mentioned that they focused less on how they spent their energy according to the upcoming road, and instead focused on navigating the environment: 'The bike gives you acceleration when not much attention is required on the road, and it stops giving you acceleration when you need to pay attention to the road. That's a good thing, as you need to engage with people' and 'You're focusing only on the environment and not on any physical effort, so it's a different sensation'. Participants then commented on the link between how they were interacting with their surroundings and how the system responded: 'It felt like the bike was drawing upon my perception of how safe the way ahead was' and 'I could see pedestrians and because I was trying to avoid them, you could feel that the bike was responding to how I was seeing the world'.

T2.2: Strategies for reaching peripheral awareness (20 units)

Participants described various strategies they engaged in to increase their peripheral awareness: 'You're trying to learn how to control that part of your mind, like learning how to flex a muscle that you're unaware of, so you've got to try lots of different things until you start to figure it out'. Some participants experimented with widening their field of view: 'When I'm looking at a nice view, I broaden my view to take it all in' and 'The system works when I dial into the peripheral awareness, I look ahead and embrace the horizon'. Others focused on their breathing patterns: 'I stared into the distance while breathing in a controlled manner and the system accelerated intermittently, then after I got my breathing under control it was continuous'. Participants played with their field of view focus and commented that 'It felt like a mind game, trying to control my focus until the system responded'. Finally, participants commented that they were not thinking about increasing peripheral awareness but were, rather, being decisive: 'You'd identified a way to go ahead, and people around you just disappeared to the side, because you've made a decision and once you have that focus, that's when the bike moves forward'.

T2.3: In sync control between the rider and the system (27 units)

I asked participants: 'Who was controlling the engine support, was it you or was it the ebike?'. One participant said: 'It felt like it was a combination of me, the bike and the environment. I noticed when I was riding that when you are decisive, when you feel clear in your mind as to where you are going, that's when you increase the speed'. Interestingly, others drew comparisons to the system as a partner: 'If I'm comparing it with a partner, I wouldn't use the word "control", I just have to be in sync without speaking with each other'. Participants in some cases controlled the engine support; this also depended on 'what the environment served you each time' as commented by some (5 units).

T2.4: Reflections on controlling the system's engine support using peripheral awareness (32 units)

Participants described the user experience of using their field of view relating to reaching peripheral awareness to increase the engine's support: '"Yes I did it!": then also it was a bit unnerving because it's out of your control? Well, of course, it's technically in your control because you made it happen by broadening your vision, I think. It feels like it's out of your control because it just fades all the same'. Participants also reflected on the ambiguous qualities Ena offered: 'That's the thing about these sorts of things you're not aware of, to me it's an ambiguous feeling, I don't have a direct switch to say to the system "go".' And one participant stated that, 'I'm affecting the system, but the system is having control over me because the system has more information about what's happening than me, which makes me think the system has maybe more control over what's happening than I do'.

Theme 3: Internal bodily signals observed by users

This theme describes 24 units and it has two sub-themes.

T3.1: I had to be in sync with myself before I could be in sync with the system (16 units)

Participants shared observations in relation to bodily processes that they observed. One participant said, 'It's quite exciting, because it feels as though all of a sudden that you've activated a different part of one of your senses, of your vision that you didn't know you had access to. It's like you've gotten access to it all of a sudden. That's pretty cool!'. Another participant noted, 'Whenever the system accelerates, my heartbeat goes up'. Comments like these suggest that participants became aware of what they were doing and how their bodies and the system were responding to one another, facilitating a space to experiment with by being in sync with themselves and the system. One participant said: 'All that the bike is doing is trying to ensure that I'm in sync with myself and my own thoughts, using my signals. I think the reason why I was disappointed is that it was me who made the system stop accelerating'. For other participants, how their body reacted was a mystery: 'The system is reacting to something in my body. How aware I am as to what my body actually did, I don't know'. It appears that tuning in and observing bodily processes in relation to the system's reaction could be intriguing for some participants.

T3.2: It's the relaxed state not the focus state (8 units)

Participants reflected on their emotional state and the influence this had on the system and experience. One participant stated: 'In other sports it's similar, you want to make good decisions and you need to control things like fear, so you do deep breathing. There's a similar sort of thing of trying to control your emotional state here'. Another participant said, 'I notice it's the relaxed state, not the focus state, that triggers the acceleration. If you're going along smoothly, you're relaxed and there's no panic or danger, it [the system] speeds up'. It appears that participants became aware of their emotional state and the influence it had on the experience.

Theme 4: Human–system symbiotic relationship

This theme describes 43 units and has two sub-themes.

T4.1: Using information directly from the user's brain was scary for some users and also interesting (27 units)

Participants expressed their opinion in relation to a future where interactive systems were able to read indirect physiological signals and automatically act on such information as Ena did. Participants described (8 units) such a future as 'scary', and they were wary of large technology companies misusing their indirect physiological signal readings. On the other hand, participants also endorsed such a future and wished to be more deeply integrated with technology due to the possible benefits. A participant stated, 'It was coming from my brain wave, but the system could slow down before I could act to "hit the brakes", it was uncanny but useful', while another participant mentioned, 'the bike was using my brain signal to control itself according to where I was looking'. These observations suggest that the user and the system were leveraging each other's skills in a symbiotic relationship to navigate the environment.

T4.2: The system kept me safe (16)

Participants described their experience in relation to the system stopping the engine support due to changes in their EEG readings caused by obstacles or distractions that resulted in the user narrowing their field of view. One participant said, 'There was no acceleration as soon as I saw the pedestrian starting to cross ... a few extra seconds with less acceleration can result in avoiding collision' and another stated, 'I felt like the system was cycling with me and slowed us down when the situation ahead changed'. This was particularly interesting as the rider was not accustomed to the system acting on information, especially since the system stopping the engine support often resulted in a bit of extra time that allowed the rider to scan the environment and find an alternative way around an obstacle. The system appeared to facilitate a form of mutual collaboration to navigate the environment.

Theme 5: Explicability and trust to support human–computer interaction

This theme describes 64 units and has three sub-themes.

T5.1: The system was intuitive for most users (20 units)

Participants described their experience in relation to controlling the system, 'It was a little bit uncertain, but that was only for a second, then I think I was surprised at how intuitive it was' and 'When the eBike stopped going, it didn't take long to look at how to reset myself to make it start again because you have to refocus and you start to know what to do to get the bike to go forward, I don't know how it happens but it just happens pretty easy'. It appears that some participants (11 units) could more easily get the engine support to trigger, while others utilised different thinking patterns that reminded them of other experiences. One participant said: 'When I play skittles it takes a lot of concentration and you are trying to work on a specific technique'. Another said: 'I don't know whether it's the sensor or whether my brain is momentarily offline'. In cases like this, it appeared that participants struggled to get the system going continuously as they were focused on one specific aspect, which affected the width of the field of view and made it difficult to reach peripheral awareness.

T5.2: I trusted the system once I realised it was helping me to be safe (24 units)

Participants reported developing trust in the system over time, especially when they realised that the system could act before they could in a situation that required slowing down to scan the environment and think about where to go. This earned the rider extra time to act on and it was translated by one participant as: 'the system is helping me to be safe' and another said: 'the bike is trying to keep you and other people safe from crashing'. Another said: 'A system that enables people to focus on the activity and enables them to avoid making mistakes'. It appears that experiencing the system acting before the rider to slow down offered riders a sense of having a safety net.

T5.3: Participants describe in their own words what the system does (20 units)

I invited participants to describe what the system dis as a form of retrospective enquiry (Hoffman et al., 2018; Molinero & García-Madruga, 2011) to elicit descriptions of their mental models and understanding of the system and their interaction with the system. Participants commented that the system supported their experience. One said: 'It understands that I don't see any threat on the road;

this makes me relaxed and it accelerates'. Others commented on technical aspects of the system; for example, 'It's looking at your brain waves and based on a specific classification of the high alpha range it triggers the engine'. Participants commented on the importance of knowing that what they think, and do, can result in different signals which the system may act upon. One participant said: 'It's very exciting, but I think it will need to be very carefully calibrated so that people understand the relationship between what they are doing or feeling or thinking with their senses and what effect that has on the given system'.

Theme 6: Participant suggestions

This theme describes 22 units and has two sub-themes.

T6.1: Participants made suggestions to combine inside of the body data with computer functions (12 units)

Participants' suggestions included: 'Combining EEG with heart rate to offer more support to the rider' and 'Sensing sweat through the handle to help you be calm'. There may be additional opportunities when it comes to focusing on the inside of the body to facilitate human–computer integration.

T6.2: Participants wished initially for more feedback via other sensory channels (10 units)

Participants wished for more feedback via other channels, such as, 'One thing that would help greatly would be a little coloured LED that glowed, that you could keep in your peripheral vision, that either changed colour or changed brightness depending on how close you were from reaching peripheral awareness'. Another took this idea to the extreme: 'I'd like it to show me, A, everything is working as expected, B, here's your value and C, is your threshold'. I chose not to use other forms of feedback so the rider could focus on the experience and tune in to their body to receive kinetic feedback via sensory receptors in the muscles, skin and joints (Taylor, 2016).

Design tactics

I now present six design tactics derived from my experiences in building and studying the system.

Tactic 1: Use peripheral awareness as a neurological state to study human performance during interactions.

Derived from themes: *The system is integrated with my brain and it can act on before I do (T1.1), The system kept me safe (T4.2), and The system was intuitive for most users (T5.1).*

In this case study I borrow a validated approach from sports science (Nan et al., 2013, 2014) to study peripheral awareness as a neurological state to create a novel prototype and study the user experience.

Takeaway: HCI practitioners can reuse the implementation description and the code offered along with the equipment listed to study changes in the user's field of view via EEG in real time during interaction. This is important as changes to our field of view affect how much we see and can influence thinking processes that enhance or hinder creativity (Ghasemi et al., 2011; Luo et al., 2008) and affect human performance (Brüers & VanRullen, 2018; Khanal, 2015). As such, I invite HCI practitioners to use peripheral awareness as a neurological state to better understand how we can support human performance in other areas within HCI, including health and wellbeing, critical systems, sports, and creative and collaborative work.

Tactic 2: Use peripheral awareness as a neurological state for integration experiences.

Derived from themes: *The system is integrated with my brain and it can act on before I do (T1.1), The system kept me safe (T4.2) and The system was intuitive for most users (T5.1).*

Prior work in human–computer integration focused 'on' the user's body (Andres et al., 2018; Hassan et al., 2017) to act on movement data, and 'around' the user's body (Andres et al., 2019; De La Iglesia et al., 2018; Sweeney et al., 2017) to act on contextual data to support the user experience. In this case study I explored a new mechanism for integration, focusing on 'inside' the user's body to design an integration system that acts on changes in the user's peripheral awareness.

Takeaway: My work suggests that HCI practitioners can use changes in a user's field of view relating to peripheral awareness as a mechanism for integration. I suggest that they should consider how the integration system extends the user's abilities in the context of the experience. Using EEG to monitor neural activity can offer access to a user's pre-attentive processing state, resulting in possibilities for integration where the system responds to a situation 'before' the user can with their body. This offers design alternatives relating to the user and the system using their sensing abilities to complement each other.

Tactic 3: Use peripheral awareness integration with kinetic feedback to facilitate users to develop connectedness with their body and the system.

Derived from themes: *I had to be in sync with myself before I could be in sync with the system (T3.1), Reflections on controlling the system's engine support using peripheral awareness (T2.4) and, In sync control between the rider and the system (T2.3).*

I chose kinetic feedback (Boucher, 2004; Taylor, 2016) as this would keep the user's eyesight free so they could focus on experiencing the system, their body and the surroundings. This enabled users to concentrate on the sensation afforded by reaching peripheral awareness, which made the eBike go faster and resulted in a kinetic feedback loop between reaching peripheral awareness to regulate engine support.

Takeaway: My work suggests that HCI practitioners can use kinetic feedback for peripheral awareness integration over mechanisms such as screen notifications, sounds and haptics, because the user can remain attentive to the experience rather than having to switch their attention to receive feedback via other sensory inputs. This, in turn, could affect the integration experience and invite users to tune in to their body, contrasting with many current technology-driven exertion experiences that take the role of sensing and offering feedback to the user via numbers, graphs and tables (Rantakari et al., 2016). Here I eliminated screens and focused on making the physical world the place where the interaction occurs between the user and the system.

Tactic 4: Use peripheral awareness integration to offer users opportunities for mastery.

Derived from themes: *It's the relaxed state not the focus state (T3.2), The experience can be elating, dramatic and surreal (T1.3), The system responded to how I was seeing the world (T1.2) and, The world became a video game (T2.1).*

In my study, participants practised reaching peripheral awareness to gain engine support to go faster as a 'fun reward', making the experience of being 'in sync' with themselves and the system 'worth it'. One of the opportunities of using indirect physiological signals such as EEG is that these are difficult to control (Mandryk & Nacke, 2016; Nacke et al., 2011) and can therefore offer a challenge for mastery.

Takeaway: My work suggests that HCI practitioners can design integration experiences by considering: 1) the system could use a feedback mechanism that does not take the user's attention away from what they are doing (see Tactic 3), as this facilitates time for the user to focus on mastering and 'tuning in' to their inner bodily processes; 2) the system could offer feedback in a way that rewards the user, such as increasing engine support; and 3) game theoretical approaches such as 'flow' (Nakamura & Csikszentmihalyi, 2002) in relation to reactions between the user and the system during integration could be used to dynamically adjust difficulty towards achievement of mastery.

Tactic 5: Use peripheral awareness integration in real time to create symbiotic-like experiences.

Derived from themes: *Using information directly from the user's brain was scary for some users and also interesting (T4.1) and Using information directly from the user's brain was scary for some users and also interesting (T2.3).*

Challenges that limit designing for symbiotic-like experiences were described by Licklider (1960) as 'the speed mismatch between humans and computers', where real-time computing equipment was expensive and heavy at the time. The reporting on this challenge was followed by 'the problem of language', where users had to communicate in computer language. Today, home and smartphone assistants require the user to learn commands to raise the system's attention and to instruct the system (for example, 'Hey Alexa ...' on Amazon Home systems). With these challenges in mind, my work suggests an implementation where the system can gain access to a user's pre-attentive processing state in real time in order to automatically act on this pre-attentive processing state before the user is able to.

Takeaway: My work suggests that HCI practitioners could address the speed mismatch challenge by studying changes in the neural activity via EEG of the user corresponding to peripheral awareness in order to access a user's pre-attentive processing state for symbiotic-like experiences. Using the same approach, it seems that HCI practitioners could address the problem of language by considering neural activity changes in relation to peripheral awareness over longer periods of time to collect time-series data. This data could offer user interactions and neural activity changes in relation to peripheral awareness, resulting in opportunities to tailor a system's reaction based on the user's experience, and removing potential language barriers between the user and the system for symbiotic-like experiences.

Tactic 6: Use peripheral awareness integration to promote users trust in the system.

Derived from themes: Reflections on controlling the system’s engine support using peripheral awareness (*T2.4), I trusted the system once I realised it was helping me to be safe (T5.2)* and, *Participants describe in their own words what the system does (T5.3).*

Most participants realised that the system stopped offering engine support as soon as a 'threat' was perceived. This often led them to feel more safe, accompanied and secure, as they had more time to act on the situation. In retrospect, participants required practice to reach peripheral awareness and gain engine support; however, once they mastered it, it afforded them a powerful feedback loop that made them feel in sync with the system. By getting to know their own signals through this feedback loop, it appears that users developed confidence in tuning in to their body, which translated to efficiently interacting with the system and a safer and more enjoyable experience.

Takeaway: My work suggests that HCI practitioners could consider the associated emotions elicited from the user when the integration system acts on the experience and focus on eliciting emotions with positive valence like joy and delight, as these can afford the user an opportunity to develop trust (Dunn & Schweitzer, 2005). In my case, the system often elicited joy when it offered engine support and it also afforded the user time to think when a threat was perceived, resulting in experiencing the system as helpful.

Creating the framework

With the study of Ena the eBike, I was interested in exploring the sub-research question: *How do we design integrated exertion systems that can act on the user's physiological data to support the user experience?*

This case study showed that facilitating an integrated exertion experience was possible by using physiological data. Using physiological data resulted in an experience where the user had some control over the system's support, as they needed to learn to tune in to their body to access peripheral awareness. This differs from the other case studies; in Case Study 1 the user's movement data controlled the system's support and in Case Study 2 it was contextual data (traffic light and speed) that informed when and how the system acted. This study showed that integrated exertion systems can offer the user increased perceptual awareness around physiological data, such as when accessing peripheral awareness, something that users do not often receive feedback on, and it is difficult to know if the user has reached it. Ena also extended the user's physical ability by offering engine support when the user reached peripheral awareness.

From Ena, the first insight I learned towards iterating the framework was that in integrated exertion experiences, HCI practitioners can design the system to extend the user's physical as well as cognitive abilities in the form of increased perceptual awareness, as the experience with Ena offered a feedback loop between the user's physiological data, the engine support and the kinetic feedback experienced as a result of going faster when reaching peripheral awareness. This insight validates the role data plays in integrated exertion experiences by offering yet a third user experience and it also contributes to developing the vocabulary to talk about user–system symbiotic-like experiences, something I describe in more detail in the framework.

The second insight from this case study towards iterating the framework was how challenging it was for some users to access their peripheral awareness in order to access Ena's engine support, suggesting that there is an opportunity for integrated exertion experiences to not only extend the user's abilities, but to challenge the user's abilities (Figure 28). In contrast to Case Study 1, where users could access engine support with ease, and also in contrast to Case Study 2, where regardless of the user's cycling experience the system acted based on the contextual data, this insight motivated reflection around the opposite ends of the X-axis shown below on the framework image.

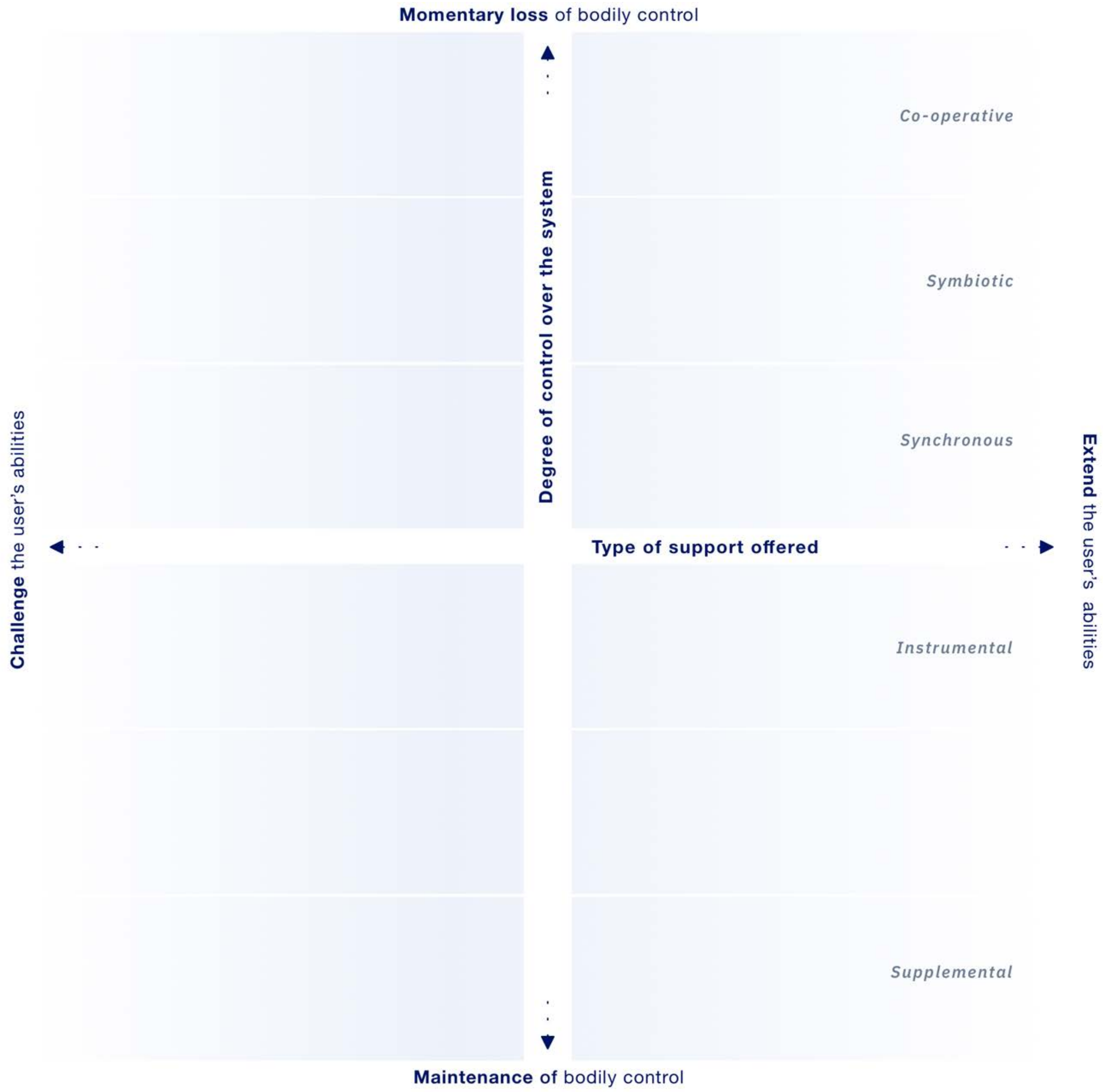


Figure 28. The third iteration towards creating the framework using insights from all Case Studies.

Summary

In this case study I presented Ena the eBike, a modified eBike system that uses physiological data; more precisely, Ena reads the user's neurological activity in relation to changes in the user's field of view corresponding to the user reaching peripheral awareness in order to regulate engine support. The experience with Ena facilitated users with extended cognitive abilities in the form of increased perceptual awareness around when they reached peripheral awareness, which made the eBike go faster, and this supported the user physically by making cycling more effortless.

Ena extended the user's physical and cognitive abilities and resulted in design knowledge to inform symbiotic user–system like experiences in integrated exertion. This knowledge was derived through a qualitative study with 20 participants using a thematic analysis approach, yielding five themes and six design tactics to analyse and design integrated exertion experiences.

This third case study confirms that using different data to facilitate the integration between the exerting body and the system can result in different user experiences. This study also shows that using physiological data can offer users some control over the system's support, in contrast to minimal control with contextual data and a lot of control with movement data.

In the next chapter I present a framework for designing integrated exertion. This framework is informed by the results of the three case studies, the feedback from reviewers when publishing each case study and through consultation with my supervisors and lab colleagues.

CHAPTER 7

Framework

Analysing and designing integrated exertion experiences.

CHAPTER 7 – Framework for Designing Integrated Exertion

In this chapter I introduce the framework for designing integrated exertion. This is a representation of the knowledge I gained through the design, implementation and study of three integrated exertion case studies. I present a visualisation of the framework using a two-dimensional chart to show the design space that integrated exertion offers for HCI practitioners. This visualisation was selected as previous works in HCI that introduced a design space containing two dimensions used this visualisation in order to describe and differentiate the resulting quadrants (Byrne et al., 2016; Marshall et al., 2016; Rekimoto, 2019).

The framework shows two dimensions. The first dimension is 'The type of support offered' and it spans *designing systems to extend user's physical and cognitive abilities* and *designing systems to challenge the user's physical and cognitive abilities*. The second dimension is 'The degree of control over the system' and it spans *designing systems that act on and cause the user momentarily loss of bodily control* and *designing systems that act on and support the user in maintenance of bodily control*. I describe and differentiate the resulting quadrants from the intersection of these dimensions with examples, reporting on twelve integrated exertion experiences which can further the general HCI understanding of designing integrated exertion experiences.

By *'Integrated Exertion'* I refer to systems where the user is investing physical effort as part of an exertion experience while the system can 'act on' data to support the exertion experience.

Why 'integration' and not 'augmentation' or 'interaction' as part of the framework name?

Users of my systems were interacting, were augmented and were also integrated. I consider these as steps in an interaction–augmentation continuum towards reaching a state of integration. I begin by drawing from the general HCI understanding of interaction (Hornbæk & Oulasvirta, 2017), which tells me that interaction happens between two entities that determine each other's behaviour. An example is between a human and a system where the human's goals determine the interaction. This quote from one of my studies depicts this situation and describes how users were interacting with my system: 'My goal was to get rid of the obstacles so that I could get the system to accelerate again'.

I also draw from augmentation (Schmidt, 2017a), the goal of which is to create human–system technologies that provide users with superhuman abilities and act like an extension of the user’s abilities. This quote from one of my studies depicts this situation: 'It feels as though all of a sudden that you've activated a different part of one of your senses, of your vision that you didn't know you had access to'. This shows that the users’ abilities were augmented through the system.

Finally, I draw from integration (Farooq & Grudin, 2016), which implies that both the human and the system draw meaning around each other’s actions to work in a partnership. This quote from one of my studies depicts this situation: 'I felt like the system was cycling with me and slowed us down when the situation ahead changed'. This suggests that the user and the system were working in a partnership.

To summarise, when designing Integrated Exertion experiences, considering this continuum is important as users can progress from interaction to augmentation towards reaching a partnership state of human–computer integration, rather than reaching a state of integration from the start.

Designing systems to extend or challenge the user’s abilities

In my work I focus on extending the user’s cognitive and physical abilities in an exertion context through a human–computer integration approach. I refer to extending the user’s cognitive abilities as the way in which the user can gain through technology increased sense-making and perception around the context of the experience (Schmidt, 2017a). This notion of extending human cognitive abilities has been reflected upon (Engelbart, 1962; Licklider, 1960) and previously explored (Schmidt, 2017a, 2017b, Rekimoto, 2019), suggesting that technology can augment human cognitive abilities in three forms: (1) *perception*, for example when a user sees the world through a thermal imaging camera, they can see heat; this is not perceptible without the thermal camera, as such technology can increase the user’s perception. (2) *Memory*, referring to the use of technology that can help users to remember information, such as setting a reminder based on time, location or events; therefore, technology can extend the user’s ability to remember. (3) *Sense-making*, for example by making sense of information in relation to our context, such as when a GPS system suggests an alternative route based on information ahead of the road. Beyond cognitive abilities, technology can also augment the user’s physical abilities, such as: supporting fine motor movement for surgery (Kumar et al., 2000; Pott et al., 2005) and supporting the user’s physical effort, for example by using an exoskeleton that reduces the metabolic rate of human walking, resulting in humans being able to walk longer distances (Collins et al., 2015). Finally, technology can also offer users extra physical strength when they need it (Kazerooni, 2005; Kazerooni & Guo, 1993).

In contrast to extending the user's cognitive and physical abilities, other works in HCI have studied how to challenge these. For example, the Bronco Matic (Marshall et al., 2011) uses the user's breathing patterns to control a mechanical bull, making the ride continuously physically demanding as the rider is challenged to concentrate on their breathing while holding tight and responding to the bull's attempts to topple them off. A further example is the Inferno Exoskeleton (Vorn, 2015), an exoskeleton that is controlled by another user, resulting in the wearer losing control over the movements of the system, which in turn moves the user's limbs. The Inferno physically challenges the user to let go of control over their own body and cognitively challenges the user's perception that 'I control my body', resulting in an entertaining experience for the wearer and the audience.

In my work I explored supporting the exerting body while cycling an electric bike through a human–computer integration approach to extend the user's abilities, by which I refer to both physical and cognitive abilities. Throughout these works participants commented about how their abilities were extended. Case Study 1, speaking to the increased physical ability of bodily strength to reach faster speeds: 'When using my torso, it is like the power comes from my leaning, and not from the engine, it makes me feel stronger'. Case Study 2, speaking to extending the user's abilities to gain increase sense-making around traffic light changing patterns in order to work together with the system to get traffic lights on green: 'A cyber-horse, you ride it like a bike and it can sense things that humans can't. Similar to bats or dolphins with echolocation'. Case Study 3, speaking to the system extending the physical ability of the user by accessing the user's neurological activity to regulate its engine support before the user could act on the situation – also extending the user's cognitive abilities by offering increased perception in relation to reaching peripheral awareness and affording the user kinetic feedback as a result of the increased speed: 'It was coming from my brain wave, but the system could slow down before I could act on to "hit the brakes", it was uncanny but useful'.

In what follows I introduce the framework's axes (Figure 29) and quadrants (Figure 30).

Designing Integrated Exertion Experiences Framework

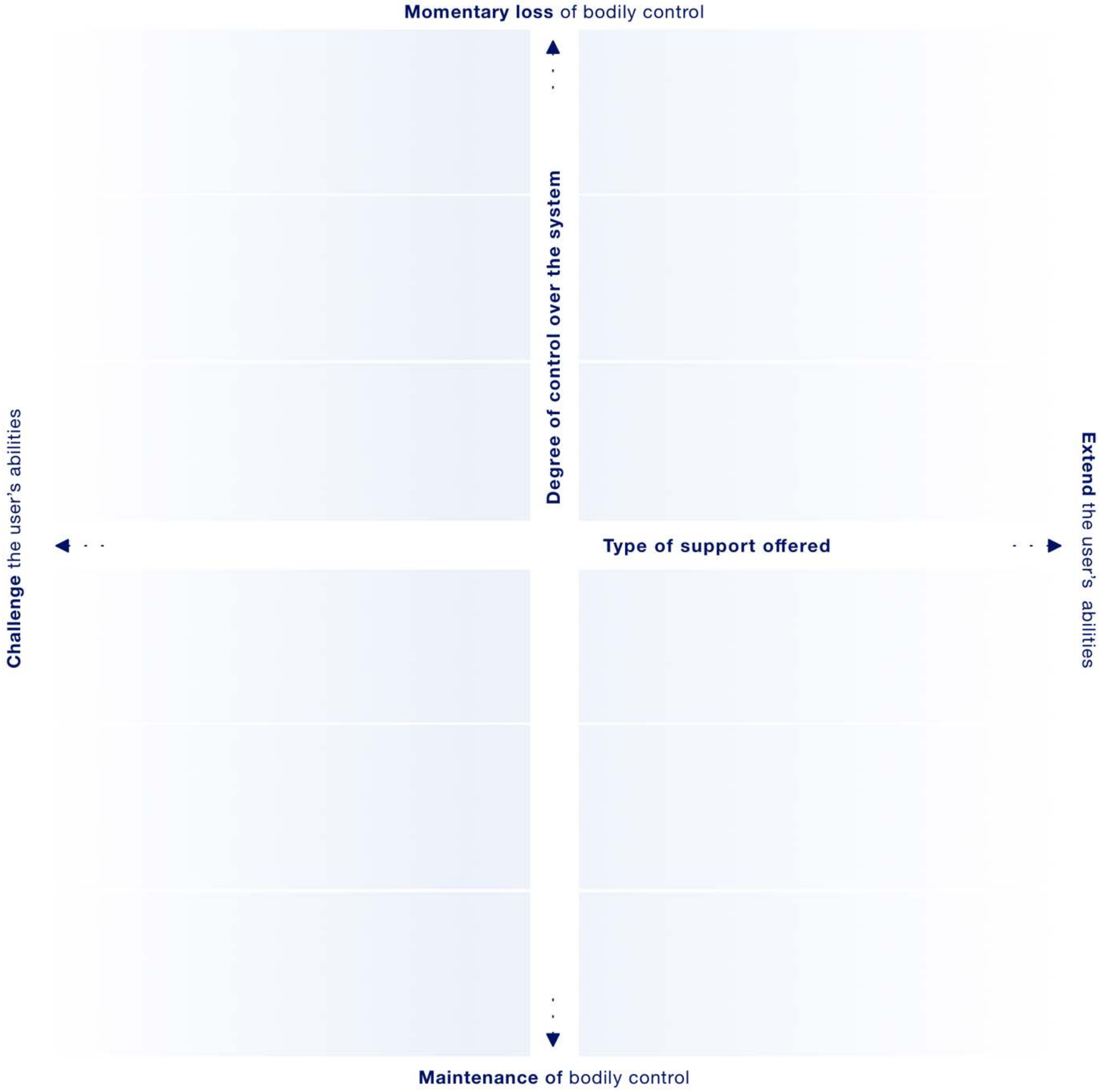


Figure 29. Introduction to the framework's axes.

The framework's axes

The X-axis represents: 'The type of support offered'; on the far right of this axis HCI practitioners can design the system to extend the user's abilities; for example, an eBike can extend the user's physical ability to go faster. On the far left of this axis HCI practitioners can design the system to challenge the user's abilities; for example, a gym spin bike can continuously become harder to pedal according to the user's cadence input, challenging the user's physical ability.

The Y-axis represents: 'The degree of control the user has over the system'. On the upper end of this axis HCI practitioners can design the system to cause momentary loss of bodily control; for example, when Ari the eBike increases engine support the user momentarily loses bodily control over the system. On the lower end of this axis HCI practitioners can design the system to support maintenance of bodily control; for example, when Ari the eBike whispers in the rider’s ears, the user maintains the same degree of control over the system.

The framework's quadrants

In this section I introduce the quadrants and corresponding user experiences (Figure 30).

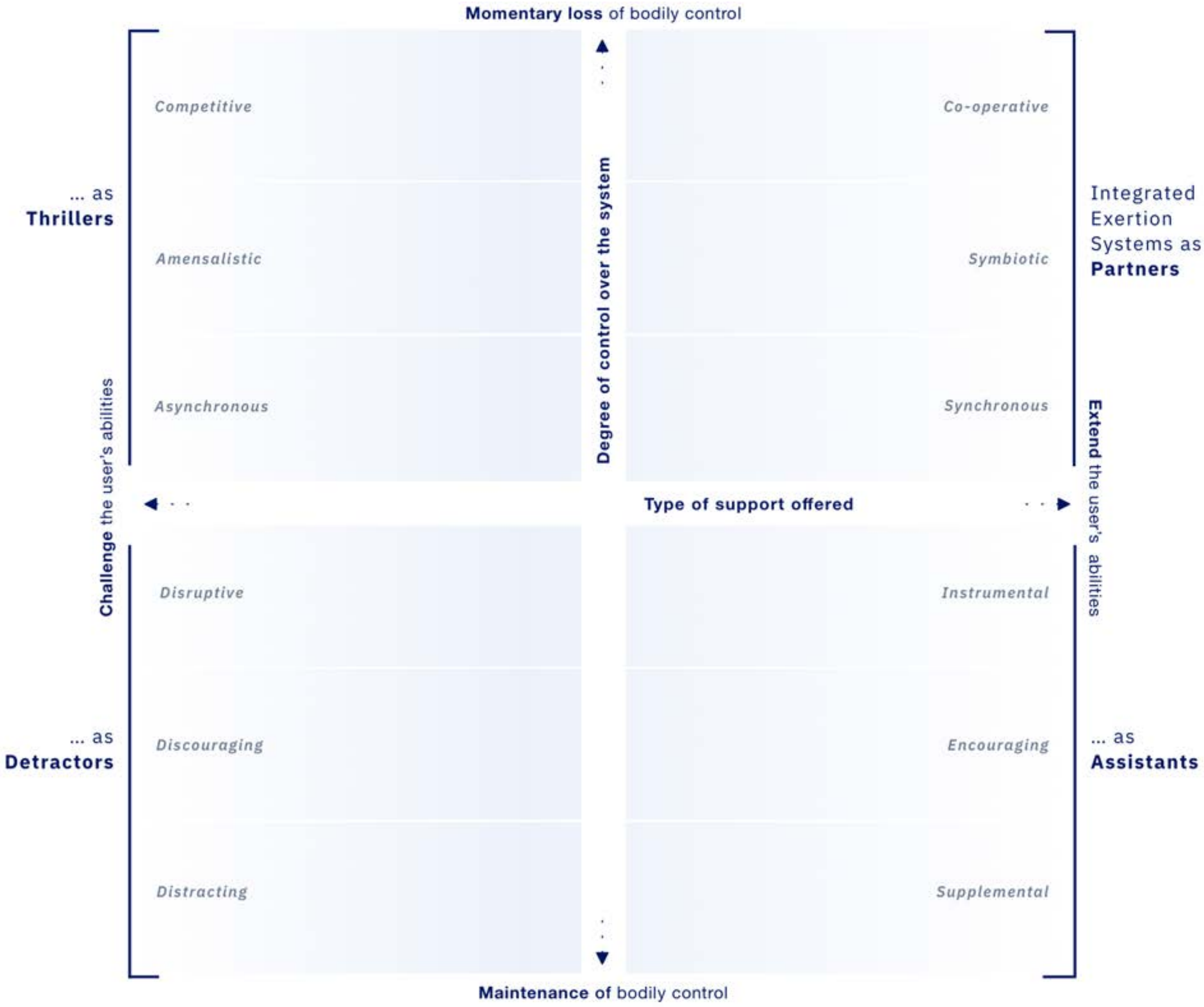


Figure 30. Designing Integrated Exertion Experiences Framework listing twelve user experiences.

The framework offers the following quadrants:

Integrated exertion systems as...

- Partners
- Assistants
- Detractors
- Thrillers

My three case studies focused on integrated exertion systems as *partners* and *assistants,* located on the right hand side of the framework which focuses on integrated exertion systems that extend the user's abilities.

Each quadrant is subdivided, for example, in i*ntegrated exertion systems as partners*, there are three user experiences *synchronous*, *symbiotic* and *co-operative* as different experiences that integrated exertion systems as partners can afford.

In what follows I introduce each quadrant with examples.

Integrated exertion systems as partners

> Integrated exertion experiences in this quadrant consist of systems that can act on the experience as an equal partner to the user to dynamically share control over the system with the user.

Designing integrated exertion systems in this quadrant

HCI practitioners should design the system to extend the physical and cognitive abilities of the user in the context of the experience – and offer the user a degree of control over the system that causes momentary loss of bodily control.

User experiences in this quadrant

Co-operative: where the system draws from contextual data around the task at hand, and from this it can act on the experience to extend the physical or cognitive abilities of the user towards achieving that task – this results in the user experiencing a high amount of momentary loss of bodily control over the system, as they do not have control over the contextual data.

Symbiotic: where the system draws from the user's physiological data, and from this it can act on the experience to extend the physical or cognitive abilities of the user – this results in the user experiencing a medium amount of momentary loss of bodily control over the system, as they do have some control over the physiological data.

Synchronous: where the system draws from the user's movement data to act synchronously with the user to extend the user's physical or cognitive abilities – this results in the user experiencing a low amount of momentary loss of bodily control over the system, as they have control over the movement data.

The user's agency over the data and its correlation with the user experience

The experience of momentary loss of bodily control is linked to the user's agency over the data. The less agency the user has over the data that the system uses to determine when to act on the experience, the less degree of control the user has over the system acting on.

The user's agency over the data can yield different user experiences, as it affects how much control the user has over the system and when and how the system acts.

Table 14 shows the three categories of data I explored:

Table 14: Data types, where the items coloured in blue were used in my Case Studies.

Case Study	**Data Category**	**Data Used**
1	Movement	Bodily inclination
2	Contextual	Traffic light and speed
3	Physiological	Electroencephalogram (EEG) for neurological activity

The user has no agency with contextual data, as the user cannot control external factors such as traffic light data, and as such cannot control when and how the system acts on this contextual data. This is what I called the 'co-operative' partner-like experience, where the system appears to be externally controlled to work with the user.

The user has a medium degree of agency with physiological data, as some inner bodily processes are difficult but partially controllable by the user, such as EEGs for neural activity and heart rate for emotional state (Mandryk & Nacke, 2016; Nacke et al., 2011). The user can learn to tune in to their body to gain some control over their physiological data and as such how the system acts. This is what I called the 'symbiotic-like' experience where the system draws from the user's physiological data and it appears to be internally controlled.

The user has a high degree of agency with movement data, as they can choose when and how to move during the experience, and this enables the system to act synchronously with the user. This is what I called the 'synchronous-like' experience.

Examples and reflections

I use my work to show examples in this quadrant and depict the user and system integration with illustrations (Figures 31-34).

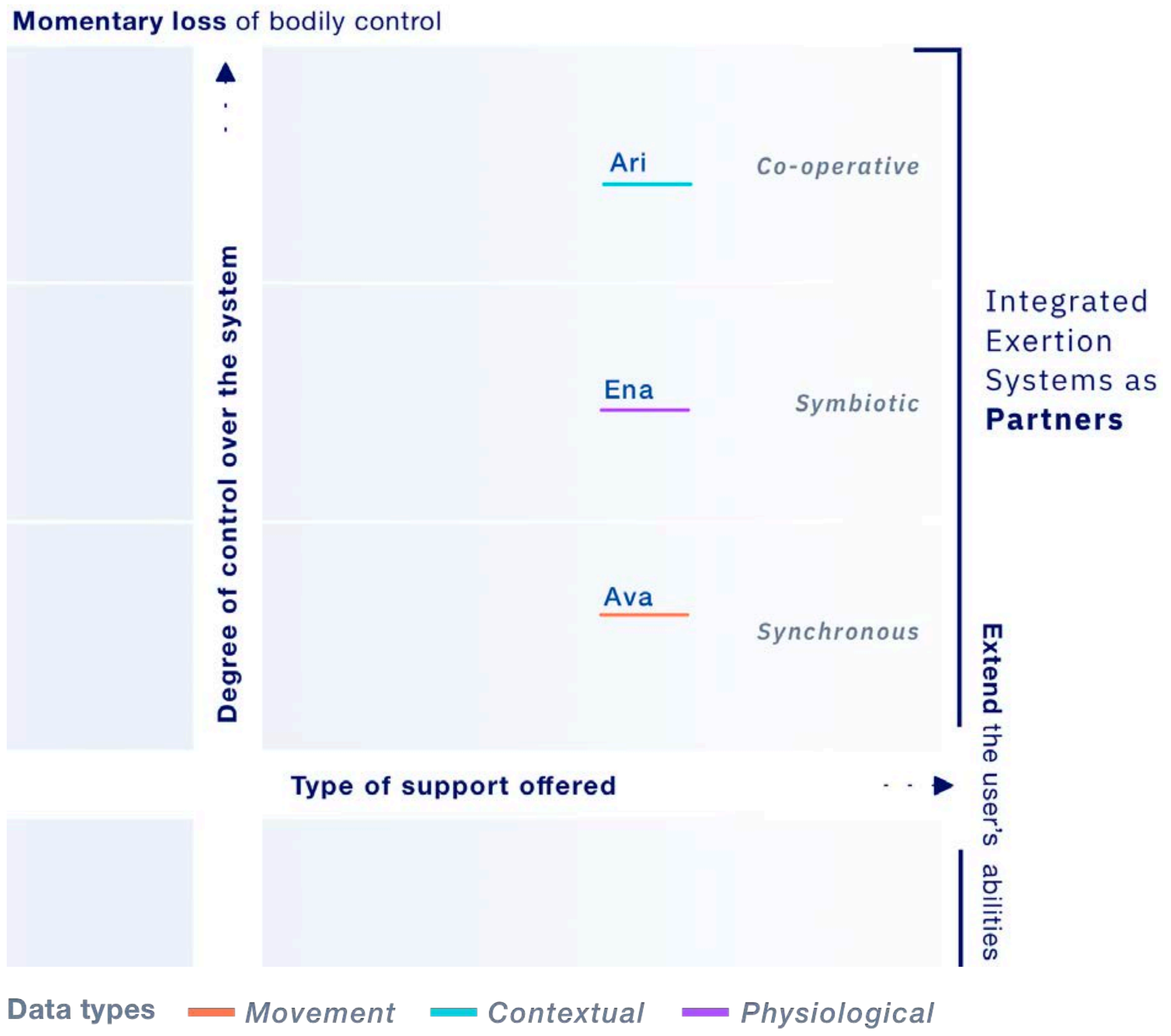


Figure 31. Integrated exertion systems as partners.

My case studies informed the framework and in particular the right hand side quadrants (integrated exertion systems as partners and integrated exertion systems as assistants), as they offer the most opportunity for exploration, because there is limited design knowledge to design integration systems that extend the user's abilities in an exertion context.

In what follows I use visualisations to represent the user experiences in this quadrant in relation to my three case studies.

I labelled Ari's experience *co-operative-like,* where the user and the system use their sensing abilities to complement each other towards achieving an outcome (Figure 32).

Co-operative experience

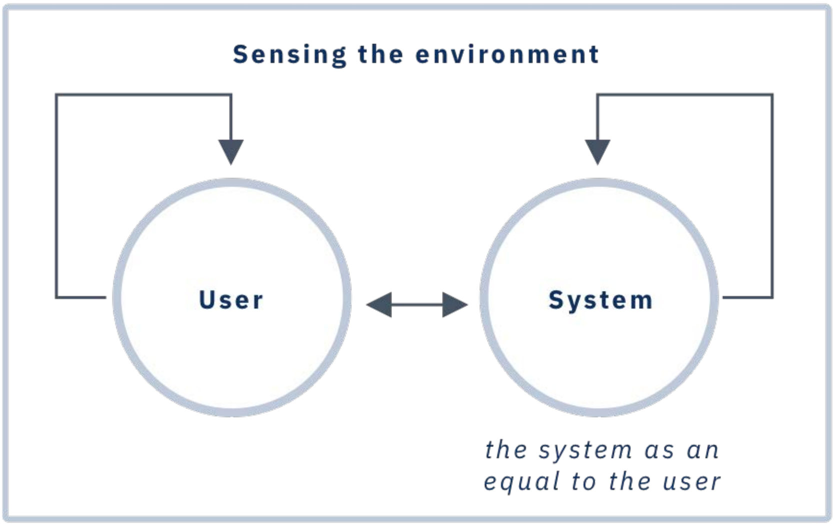


Figure 32. Co-operative user experience visualisation.

Case Study: Ari the eBike is designed to extend the user's physical abilities by increasing engine support in relation to the rider's speed and the traffic light changing patterns. Ari also extends the user's cognitive abilities by facilitating the user to gain increased sense-making in relation to their speed and the traffic light changing patterns by whispering in the rider's ears to slow down a little so that the rider can regulate their speed to catch traffics lights on green. When Ari increases engine support, this causes the rider to *momentarily lose bodily control over the system*. Due to Ari using contextual data (traffic light and speed), users reported that Ari felt like it was externally controlled. This gave riders more momentary loss of bodily control than Ena, as I explain next.

I labelled Ena's experience s*ymbiotic-like,* where the system draws from the user's physiological data as they sense the environment to regulate actuation support towards benefiting the user (Figure 33).

Symbiotic experience

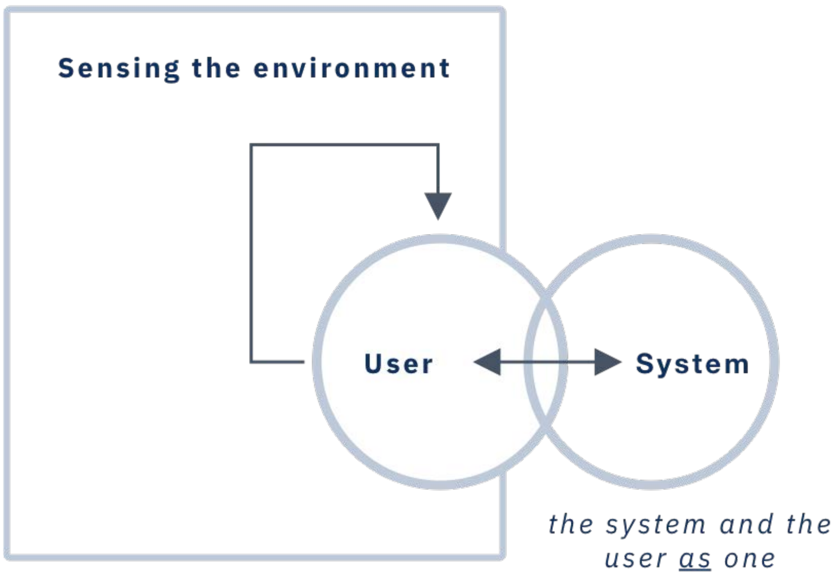


Figure 33. Symbiotic user experience visualisation.

Case Study: Ena the eBike is designed to extend the user's physical and cognitive abilities by increasing engine support when the rider's EEG signal shows that they are in a peripheral awareness state. Ena offers engine support to assist the rider to cycle with more ease, the increased engine support makes the system go faster and offers kinetic feedback to the user - facilitating a feedback loop that indicates to the rider that they are peripherally aware. When the user loses peripheral awareness due to narrowing their vision to focus on an upcoming threat such as another bike or a vehicle, Ena stops engine support immediately as it is reading directly from the user's EEG. Ena's regulation of the engine support can cause the rider to *momentarily lose bodily control over the system*. Due to Ena using physiological data (EEG), users reported that Ena felt like it was internally controlled. This gave riders a sense that their *momentary loss of bodily control over the system* was partially under their control.

I labelled Ava's experience *synchronous-like*, where the system draws from the user's movement data to synchronously regulate actuation support as the user moves (Figure 34).

Synchronous experience

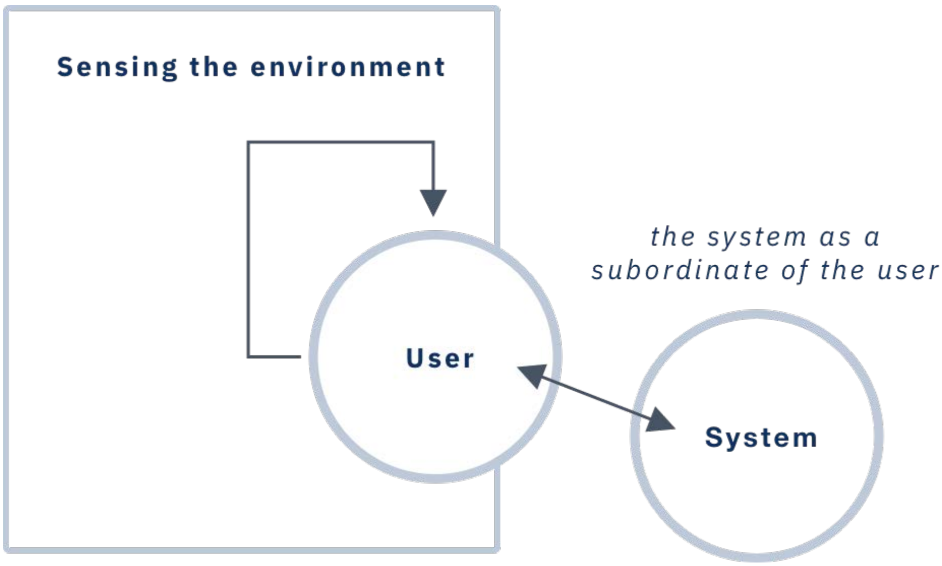


Figure 34. Synchronous user experience visualisation.

Case Study: Ava the eBike is designed to extend the user's physical abilities by increasing engine support simultaneously as the user leans forward. Ava's engine support results in the rider momentarily losing bodily control over the system, as the rider adjusts to the extra speed increase controlled using their body. Ava differs from Ari and Ena in that it acts synchronously with the rider's movement requesting extra speed, in contrast to being externally controlled using contextual data or internally controlled using physiological data. The momentary loss of bodily control over the system in Ava's case is much less than with Ena or Ari.

In summary, all systems in this quadrant can extend the users' abilities and result in different levels of momentary loss of bodily control when the system acts on the experience. This momentary loss of bodily control is linked to the user's agency over the data.

Integrated exertion systems as assistants

Integrated exertion experiences in this quadrant consist of systems that can act on the experience as an assistant to serve the user, while the user retains control over the system.

Designing integrated exertion systems in this quadrant

HCI practitioners should design the system to extend the physical and cognitive abilities of the user in the context of the experience – and offer the user a degree of control over the system that supports maintenance of bodily control.

User experiences in this quadrant

Instrumental: where the system can draw from contextual, physiological or movement data around the task at hand, and from this it can act on the experience to extend the physical and cognitive abilities of the user by passing on 'instrumental' information that the user can action towards achieving the task – the user maintains bodily control over the system.

Encouraging: where the system can draw from contextual, physiological or movement data around the task at hand, and from this it can act on the experience to extend the physical and cognitive abilities of the user by offering 'encouraging' information towards supporting the user in achieving the task – the user maintains bodily control over the system.

Supplemental: where the system can draw from contextual, physiological or movement data around the task at hand, and from this it can act on the experience to extend the physical and cognitive abilities of the user by actuating 'supplemental' information that the user can benefit from – the user maintains bodily control over the system.

Examples and reflections

I use mine and others' work as examples in this quadrant (Figure 35).

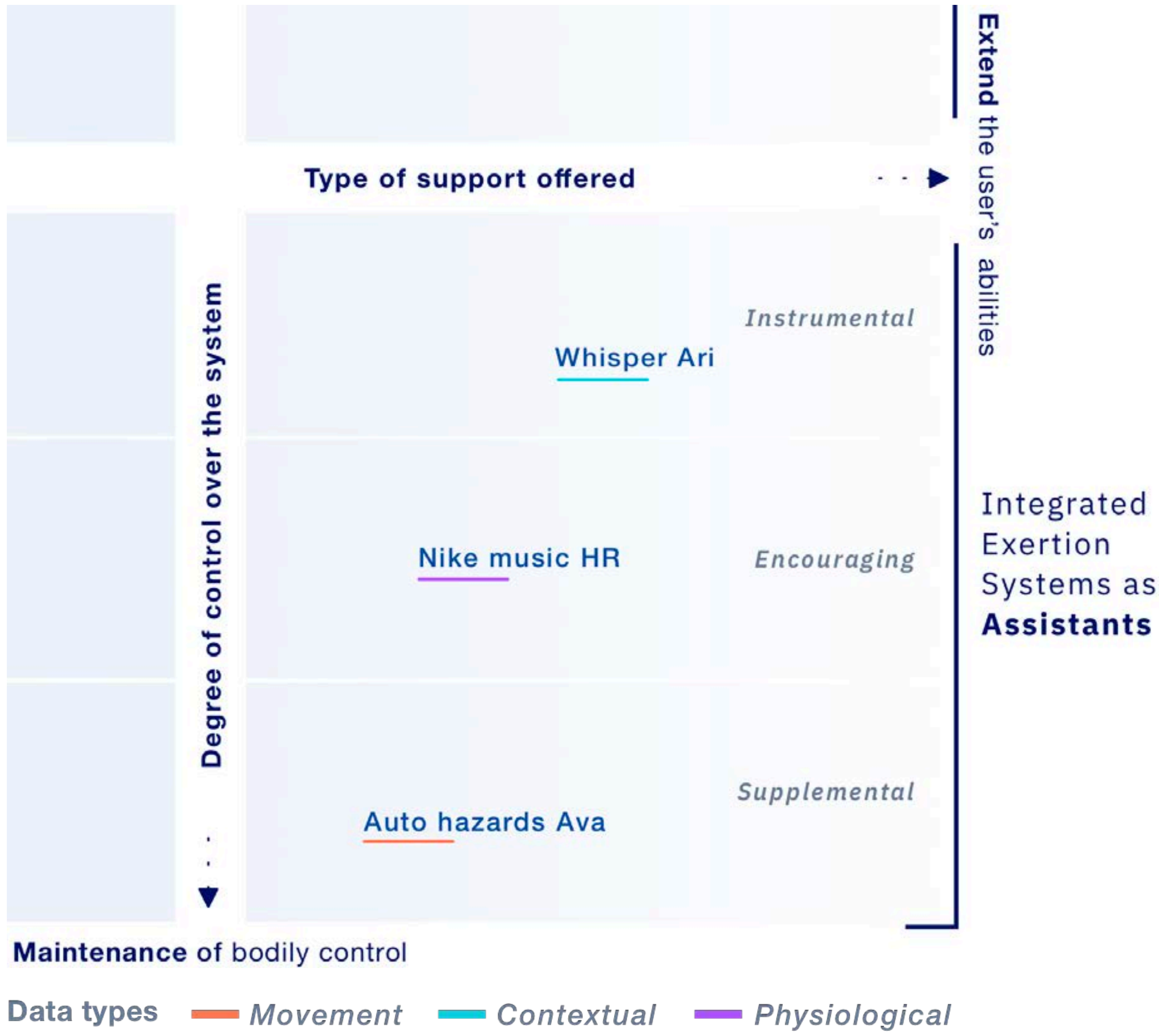


Figure 35. Integrated exertion systems as assistants.

Two of my case studies offered features that extended the user's abilities and were designed to maintain the user's control over the system. Participants reported these features as 'smart' and 'timely', in relation to the extra abilities that they afforded the user during the experience. This notion of systems that can assist the user during the experience has been explored by Kruger (2017), emphasising that humans can offload tasks to assistant systems to reduce workloads, and that the user needs to be aware of the abilities of the system in order to effectively use the assistance offered by the system and benefit during the experience. Johnson (2014) supports this notion and suggests that assistive systems should behave like a teammate, supporting the user to achieve their goals during the experience. I discuss below how my system assisted the user during the experience.

Ari the eBike: Ari acts on in the experience by whispering in the rider's ear to pass on instrumental information that the rider can action to regulate their speed and catch traffic lights on green. Through this the rider gains sense-making, as such extending their cognitive abilities to regulate their cycling efforts. In this case, when Ari acts, the user maintains bodily control over the system.

Ava, the eBike: Ava's automatic hazard lights are also placed in this quadrant, as the system's participation does not affect the user in maintaining bodily control over the system. This participation is designed to extend the user's physical abilities by turning on the hazard lights automatically with the aim of making others more aware of the rider as they are standing up pedalling and may become wobbly because eBikes are heavier than regular bikes.

The difference between Ari's ('Whisper Ari' on Figure 35) and Ava's ('Auto hazard Ava' on Figure 35) placement on the framework's Y-axis is that in the *instrumental* section of the quadrant, the user needs to execute the instrumental information into an action to gain the benefit. In the case of Ava, the system can actuate *supplemental* information to support the user in a way that does not require the user to execute an action or adjust bodily control over the system. This results in the user maintaining bodily control over the system.

Nike music HR (2020): This app offers in-run cheers from friends and guided running based on the user's previous performance through this offering of messages that encourage the user to pick up the pace. This can assist the user to keep running, as if offering extra cognitive and physical strength through an encouraging approach.

Integrated exertion systems as detractors

> Integrated exertion experiences in this quadrant consist of systems that can act on the experience as a detractor to draw the user away from the situation, while the user retains control over the system.

Designing integrated exertion systems in this quadrant

HCI practitioners should design the system to challenge the physical and cognitive abilities of the user in the context of the experience – and offer the user a degree of control over the system that causes maintenance of bodily control.

User experiences in this quadrant

Disruptive: where the system can draw from contextual, physiological or movement data around the task at hand, and from this it can act on the experience to challenge the physical and cognitive abilities of the user by interrupting and drawing away the user's attention from the task at hand – the user maintains bodily control over the system.

Discouraging: where the system can draw from contextual, physiological or movement data around the task at hand, and from this it can act on the experience to challenge the physical and cognitive abilities of the user by offering discouraging information towards discouraging the user in achieving the task hand – the user maintains bodily control over the system. This area appears to be under-explored according to my search for examples.

Distracting: where the system can draw from contextual, physiological or movement data around the task at hand, and from this it can act on the experience to challenge the physical and cognitive abilities of the user by offering a distraction from the task at hand – the user maintains bodily control over the system.

Examples and reflections

I borrow from others' work to discuss this quadrant (Figure 36).

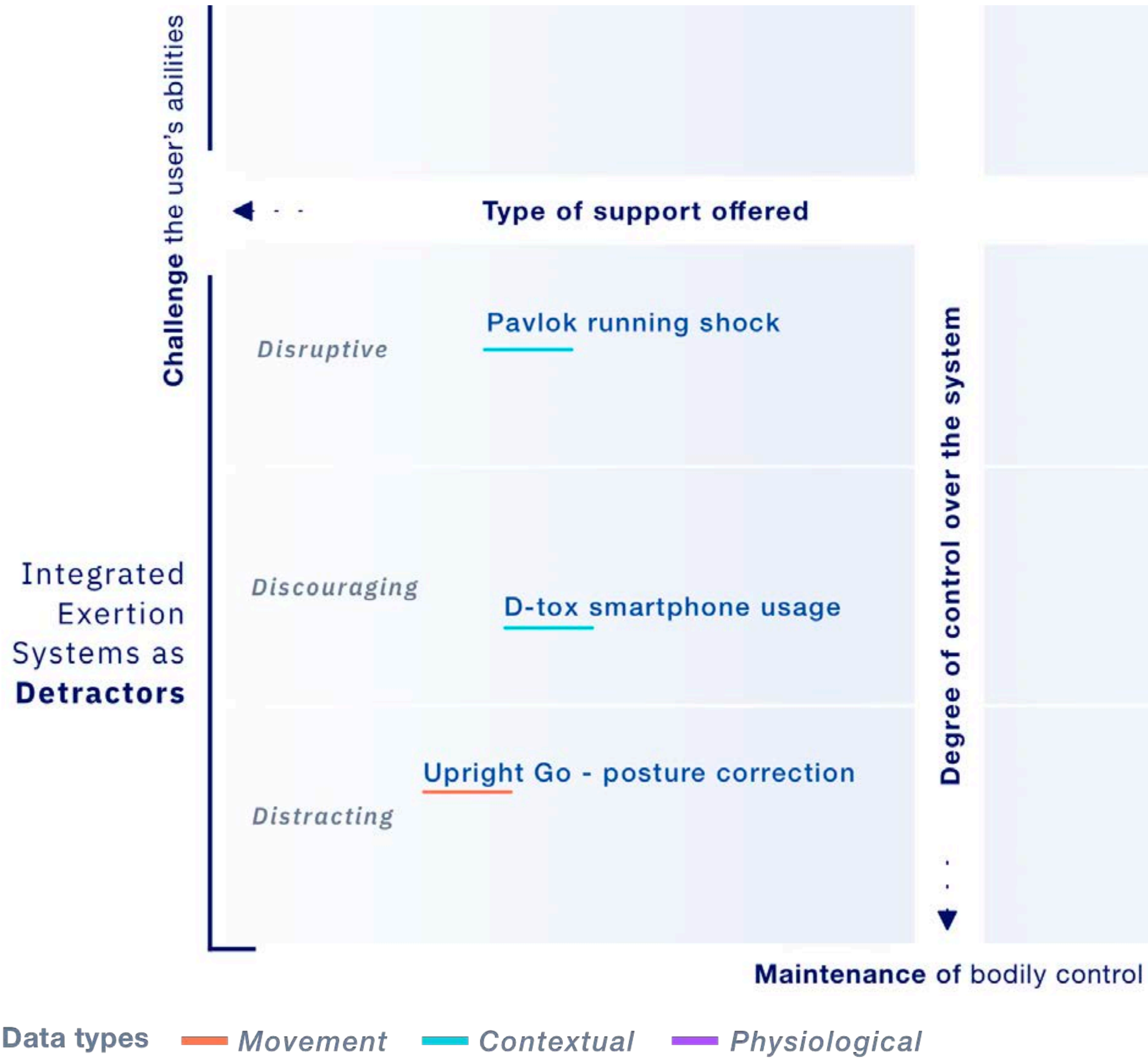


Figure 36. Integrated exertion systems as detractors.

Integrated exertion systems in this quadrant detract the user from the experience at hand through their action, drawing away the user's attention to challenge their cognitive and physical abilities. Systems that have been designed to distract the user from the experience appear to be associated with persuasive technology, which aims to challenge the user's attitudes and behaviours through interventions (Meschtscherjakov et al., 2016). Two such interventions revolve around using electric shocks and haptic patterns, as I discuss below.

The Pavlok electric shock system (2018) is designed to challenge the user's cognitive and physical abilities by abruptly delivering an electric shock. This is triggered by the user configuring it around certain tasks, like running too slowly based on a given speed and GPS tracking. The user is detracted from the experience while maintaining bodily control over the system.

D-TOX smartphone usage (Lee et al., 2017) is a projecting lamp that discourages the user from using their smartphone by drawing from contextual data around the placement of the device within the projecting lamp. When the user is on their device for too long, the system turns on a consistent red light, and when the user is not on their device, pleasant lights and animations serve as a reward for the user. While this system offers a glimpse of a ‘discouraging’ user experience that challenge the user’s abilities, I recognise that it does not focus on an exertion component. It appears that designing integrated exertion experiences that challenge the user’s abilities through a discouraging approach is an under-explored area as limited is found.

The Upright Go (2019) uses movement data; as the user slouches, the bodily inclination trigger a haptic pattern that distracts the user from the experience they are currently doing and challenges the user to correct their posture. As such, the user can choose to straighten up and correct their posture or ignore the haptic feedback.

Besides the differences in how these systems act to distract the user from the experience, the systems in this quadrant so far are designed for habit development and improvement to persuade the user through the interventions, while they are also designed to support the user in maintaining bodily control over the system.

Integrated exertion systems as thrillers

Integrated exertion experiences in this quadrant consist of systems that can act on the experience as an opponent to the user to fight for control of the system with the user.

Designing integrated exertion systems in this quadrant

HCI practitioners should design the system to challenge the physical and cognitive abilities of the user in the context of the experience – and offer the user a degree of control over the system that causes momentary loss of bodily control.

User experiences in this quadrant

Competitive: where the system draws from contextual data around the task at hand, and from this it can act on the experience to challenge the physical or cognitive abilities of the user towards achieving that task – this results in the user experiencing a high amount of momentary loss of bodily control over the system.

Amensalistic*: where the system draws from the user's physiological data, and from this it can act on the experience to challenge the physical or cognitive abilities of the user – this results in the user experiencing a medium amount of momentary loss of bodily control over the system.

> **__Amensalism__ is a type of symbiotic relationship where one species (the system in this case) provides a means to deteriorate the survivorship or fitness of another species (the user) without impacting its own fitness (Munguia et al., 2009).*

Asynchronous: where the system draws from the user's movement data to act asynchronously with the user to challenge the user's physical or cognitive abilities – this results in the user experiencing a low amount of momentary loss of bodily control over the system.

Examples and reflections

I borrow from others' work to discuss this quadrant (Figure 37).

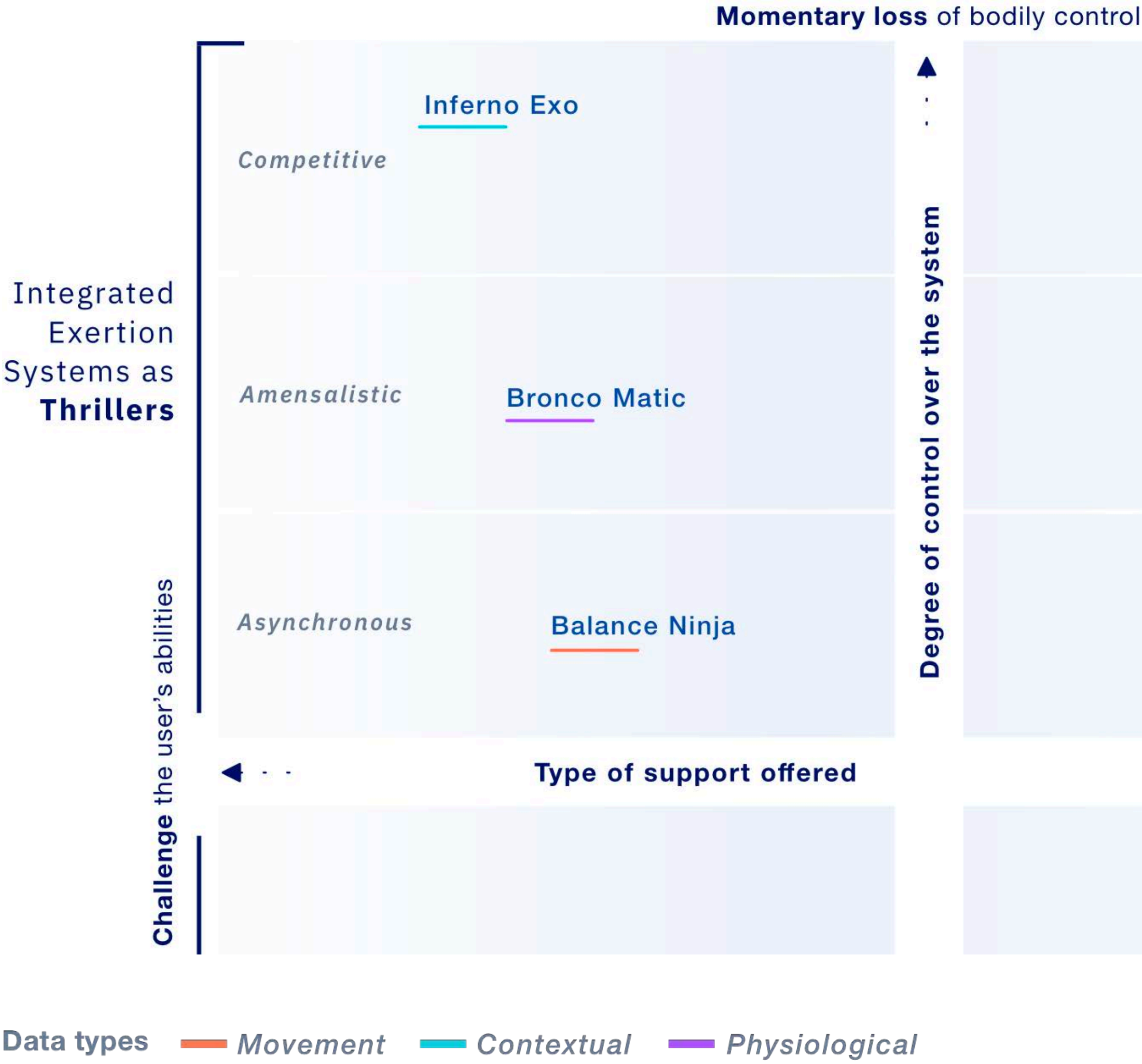


Figure 37. Integrated exertion systems as thrillers.

Integrated exertion systems in this quadrant result in systems that offer thrilling experiences to the user by challenging their cognitive and physical abilities, causing the user to momentarily lose bodily control over the system. Designing experiences to elicit from users thrill through discomfort has been previously explored by Bendford (2012), suggesting that it can lead to fun, engaging and enlightening experiences for users. Byrne (2016) also explored this area through facilitating users to experience digital vertigo, reaching uncomfortable levels that yielded entertaining and novel experiences.

The Inferno Exoskeleton (Vorn, 2015): this is an exoskeleton that forces the wearer to dance using contextual data, where another user provides directions by manipulating the limbs of a physical doll, resulting in the limbs of the exoskeleton moving and forcing the wearer to move. The Inferno Exoskeleton causes the wearer to momentarily lose bodily control over the system. The Inferno Exoskeleton affords the user a thrilling experience while challenging their physical and cognitive abilities to let go of bodily control.

The Bronco Matic (Marshall et al., 2011): this is a mechanical bull ride that has been modified to read the rider's breathing rate (physiological data) to inform how aggressively the bull turns and spins around to topple the rider off. The Bronco Matic challenges the physical abilities of the rider as they need to fight against the bull's attempts to topple them off, and also challenges the rider's cognitive abilities as they need to focus to control their breathing rate. This is what I call symbiotic-amensalistic experience, where the Bronco Matic draws from the user's physiological data and aims to deteriorate the user's survivorship. The Bronco Matic affords a thrilling experience while it challenges the user and it causes them to momentarily lose bodily control over the system.

The Balance Ninja (Byrne et al., 2016): this is a system that uses galvanic vestibular stimulation (GVS) to afford the user the sensation of vertigo via an electric frequency delivered on the mastoid bone behind the ear. The system delivers the electrical current based on bodily movement data and affords the user a thrilling experience that challenges their physical ability to remain balanced and their cognitive ability to focus on balancing their body.

The systems in this quadrant so far are designed for entertainment and to challenge the user's abilities in order to afford thrilling experiences.

The framework featuring all the systems discussed in this chapter

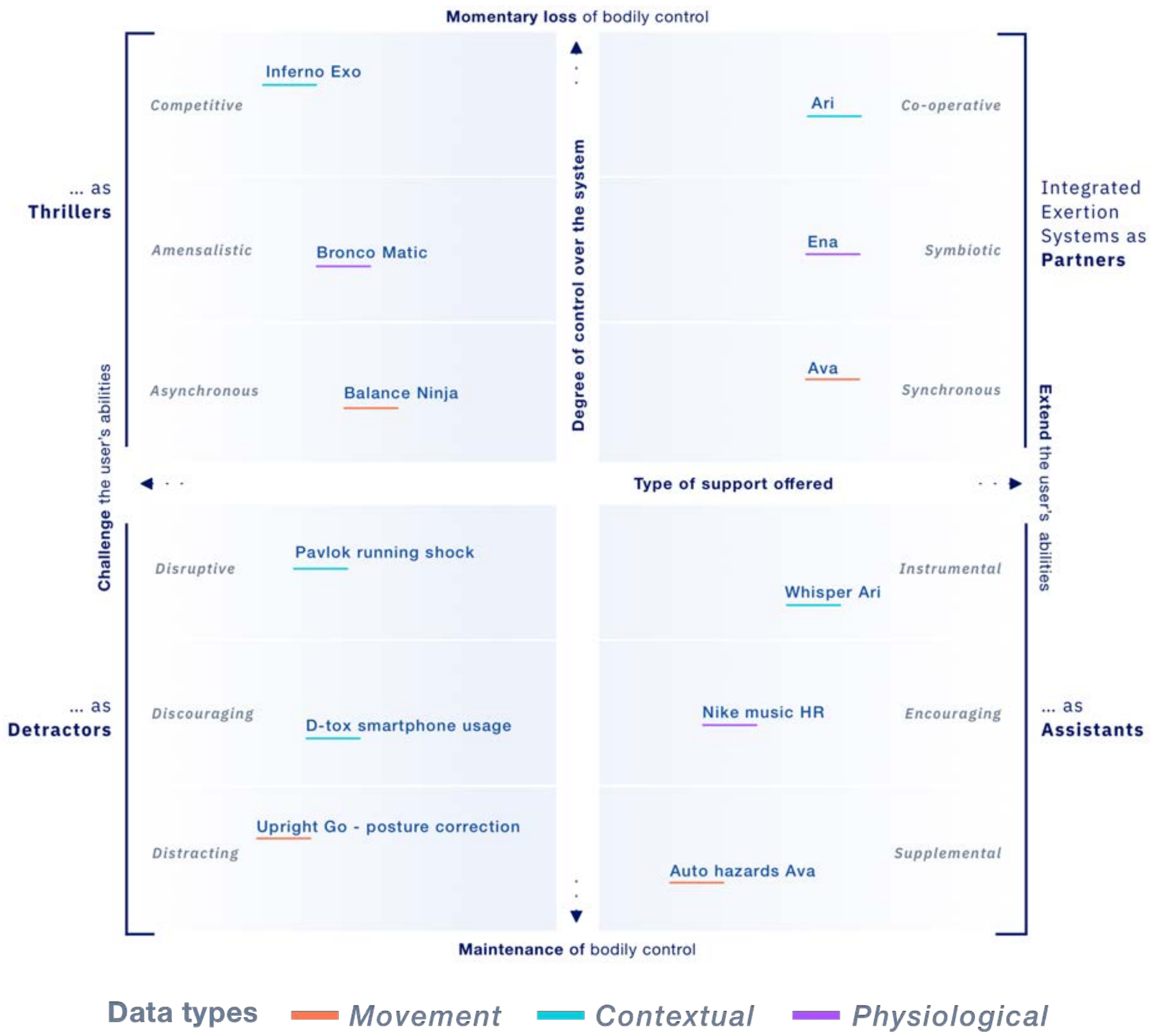


Figure 38. The framework showing all the systems used to explain the quadrants.

The framework's dimensions

The framework also offers design dimensions; these are opposite ends that HCI practitioners can design for within a design space. In my case the dimensions go across two quadrants, for example, *co-operative* and *competitive* are on opposite ends, forming a design dimension. These design dimensions offer HCI practitioners alternatives within the design space of integrated exertion. In Figure 39, the first row of the framework is coloured as an example of a design dimension.

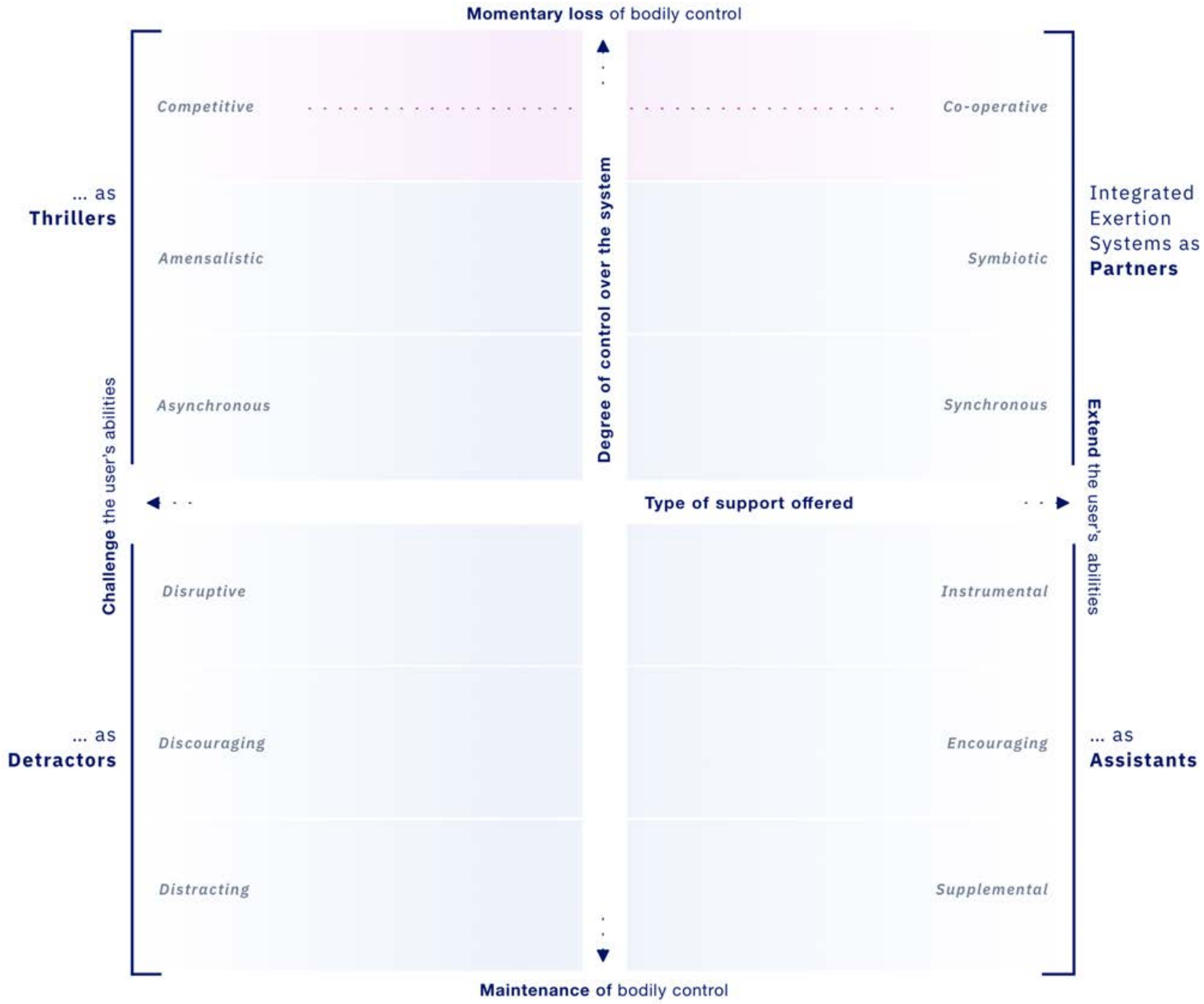


Figure 39. Colour-coded design dimension across two quadrants on the framework.

There are six dimensions in total:

Table 15: Six cross-quadrant design dimensions presented as part of the framework.

Dimensions	**Opposite design alternatives**	
Cross-quadrant	***Integrated exertion systems as thrillers***	***Integrated exertion systems as partners***
1	Competitive	Co-operative
2	Amensalistic	Symbiotic
3	Asynchronous	Synchronous
Cross-quadrant	**Integrated exertion systems as *detractors***	**Integrated exertion systems as *assistants***
4	Disruptive	Instrumental
5	Discouraging	Encouraging
6	Distracting	Supplemental

Considerations around the user's experience, risks and opportunities when designing integrated exertion experiences

In this section I describe details of the user's experience when interacting with integrated exertion systems and offer design tactics that HCI practitioners can apply.

Reflecting on integrated exertion using Norman's three level of design: visceral, behavioral and reflective

It takes practice to reach a state of integration where the user and the system act in a partnership effortlessly and merge as one, and this practice can be better understood through the three levels of the design model proposed by Norman (2004). The 'visceral' design is the first level of the model and it refers to the perceptible qualities of the system and the associations it can evoke from a user. For example, the visceral experience with Ari the eBike, which did not require the user to wear extra hardware, is more likely to be associated with a standard eBike and the experiences that eBikes evoke for a user. In contrast, the visceral experience with Ena, the eBike might be one of anticipation, ambiguity and marvel, because eBikes and EEG caps do not often come together; this juxtaposition affects the visceral experience of the user. In hindsight, the visceral experience of the EEG cap and the experiences it evokes could have contributed to furthering the notion of integration between the user and the system, priming the user to prepare for integration via their neural activity. As such, visceral design qualities could be considered in future work when designing integrated exertion systems, to assist users in commencing the transitional journey from novice to becoming integrated with the system.

The second level of the model focuses on the 'behavioural' experience. The behavioural experience concentrates on the emotions elicited from the user as they experience the system, such as: does the system make me feel safe, joyful, in control, or in danger? In the systems explored in this thesis, the system can elicit a mixture of emotions from the user as they travel the interaction, augmentation, and integration continuum. Along the continuum, the user becomes more skilled towards a merger of human and machine that can perform tasks jointly. The behavioural design qualities varied across the three systems in my thesis. With Ava, participants reported a joyful and superpower-like experience, as they could use their torso to lean forward and increase engine support. The turbo sound amplified the sensation of acceleration and led to make-believe moments (Deterding 2016). The experience with Ava was pleasurable, fun and adventurous.

With Ari, the experience was quite different as the user had less control than with Ava or Ena. Ari required more practice, as it could increase engine support when the speed was too low to get to the next traffic light while it was still green, and it could also communicate via bone-conducting headphones when the speed was too fast to get to the next light on green. The experience with the bone-conducting headphones was 'intellectual', according to Norman who refers to systems that can make a recommendation without controlling the experience and invite the user to examine the recommendation to determine acceptance or rejection of the recommendation (Norman 2009). In my framework, under "integrated exertion systems as assistants", the experience of the bone-conducting headphones is placed on 'instrumental experiences', where the system can pass on instrumental information that the user can choose to action according to the context of the experience. Importantly, in instrumental experiences, as with intellectual experiences, the user is in control of the system and determines to action or reject the recommendation.

Behavioural qualities are critical to people's engagement with a system and the spectrum of emotions and associations constructed from their experience. Participants of my studies expressed their experience in some cases as "the system is helping me to be safe", or "the system does not have eyes, you have eyes, so you are working together as buddies". The emotional qualities experienced by a user with the system can contribute to increase or decrease trust in the system (Dunn & Schweitzer 2005). I believe that this trust can mediate a relationship with the system and can hinder or promote reaching a state of integration. The behavioural qualities are continually evolving through practice with the system. This is particularly so in integration experiences when the system participates in the experience alongside the user. It can shake up the constructed visceral and behavioural models in terms of what the system can evoke and about what it elicits from the user. This results in a recalibration of the visceral and behavioural models that reflect the evolving experience with the system towards becoming integrated.
The third and final of the three levels of the design model by Norman (2004) is the 'reflective' design level. The reflective experience is the rationalization of the system and the experience, and it is interwoven with the visceral and behavioural experience. For example, the user can reflect on what the system evokes for them at a visceral level. The user can also reflect on their experience with the system, as they did during the study of each of my systems.

This reflection varied across my systems, and in some instances, it appears to be linked with the level of control the user had over the system. With Ava, the user had the most control out of the three systems, and the reflective experience about integrating with the system was often focused on how easy and fun it was to get extra engine support as if it came from within their body. With Ena, the control over the engine support was ambiguous in that the user could not fully master their neurological activity that corresponds to changes in peripheral vision. This is because instinctive reflexes that assist us to remain safe while navigating the environment kick in and take the user out of a peripheral vision state to focus on potential threats, resulting in neurological signal changes that make the extra engine support stop. The reflective experience with Ena concentrated on how users were trying to access their peripheral vision and how the environment played a role in making this easier or harder. This reflection surfaced learnings about how their internal state could become translucent and blended with the external environment towards reaching integration. With Ari, the experience felt as though it was externally controlled, because Ari was drawing from the environment simultaneously with the user. However, the user and Ari had different sensing abilities. In Ari's study, I looked at integrating them to facilitate a space where the user and the system could merge in a cycling context to cross traffic lights on green. The reflective experience with Ari concentrated on trying to understand why and when the system was going to increase engine support or when it was going to recommend to the user to slow down.

This reflection began with describing their experience as “conflicting” with the system and being “fiddly”, as it is often the case with mastering interactive systems and exertion-based activities, where practice improves our experience. At the start of the trial, participants needed to gain skills and finesse their movements to control their extended body with the system; this is when the user's actions are at a conscious level, requiring a thoughtful process of coordination to determine what actions or movements go well in a particular situation (Spiegel 2019). The reflection then evolved to describe reaching an experience where the user is skilled and familiar with the system, and their actions can reach a subconscious level (Norman 2009), where the user’s actions and movements are harmoniously and effortlessly combined with the system to perform tasks jointly. I describe more about this transitional journey in the following section.

The novel integrated exertion systems in this work serve as provocations to envision supporting the exerting body through an integration approach. At the same time, they allow us to begin accumulating learnings about the visceral, behavioural and reflective experience of integrated exertion systems. These qualitative learnings accompany the prototypes presented in my thesis towards extending the library of human-machine integrations available to designers and researchers.

Our sense of agency and how it is affected by integrated exertion systems

I borrow from previous works that have studied humans' sense of agency at length (e.g., (Coyle et al., 2012; Ebert & Wegner, 2010; Haggard & Tsakiris, 2009; Moore et al., 2009)) suggesting the following definition:

The experience of agency is defined as a person's innate sense of being in control of their actions and through this control of being responsible for, or having ownership of, the consequences of those actions (Coyle et al., 2012).

The experience of agency in HCI has become more relevant to the everyday systems we interact with and design for. This is due to technology advances that allow systems to act on the experience – as if having an artificial sense of agency – and through their actions bring changes to the world and, as such, to our experiences and own sense of agency (Farooq & Grudin, 2017; Johnson et al., 2014; Krüger et al., 2017; Kuijer & Giaccardi, 2018; Lopes et al., 2015). I and others argue that this artificial sense of agency can hinder or promote the user experience, as our interactions with technology are affected by how much we trust the system's actions in relation to the goal of our experience (Dunn & Schweitzer, 2005; Kuijer & Giaccardi, 2018; Siau & Wang, 2018). As such, we have entered a new era in which interactive systems can act on the experience alongside the user, and HCI practitioners are at the forefront of the study and design of what this relationship between humans and systems can develop into.

When we make voluntary actions, we tend not to feel as though they simply happen to us, instead we feel as though we are in charge. The sense of agency refers to this feeling of being in the driving seat when it comes to our actions (Moore, 2016).

In the case of Ari the eBike (Chapter 5), users experienced momentary loss of bodily control over the system when Ari increased engine support to go faster. This afforded users a new experience that challenged their sense of agency, as regular eBikes do not sense contextual information to determine when to increase engine support. To further understand the intricacies of the user and the system working together, in the next section I describe how the bodily awareness of the user is extended to include sensing through the body of the eBike.

Our extended body with the system

As the rider cycles and becomes more experienced, their bodily awareness extends to include sensing through the body of the bike, similar to a blind person feeling the floor ahead through their walking stick. This extended bodily awareness suggests that the tool, in my case the eBike, can become semi-invisible as there is a strong correlation between the visual and sensory experience of the user's actions as they cycle and move through space, withdrawing the presence of the tool (Berlucchi & Aglioti, 1997; De Preester, 2011; Krüger et al., 2017). This sense of extended bodily awareness is important when we consider now that the system can act on the experience, due to the semi-invisibility of the tool and the close proximity of the two bodies – the user and the eBike. When the system acts in the experience to support the user, it reveals itself back from semi-invisibility to be present in the experience. In doing so, it brings about change to the world through its actions, and also to the user's sense of agency. This interesting situation leads to the idea that the user and the system are working together in a partnership (Farooq et al., 2017; Kuijer & Giaccardi, 2018) and it requests that the user gradually adjusts through practice in order to reap the benefits of the partnership; however, this takes time.

Reaching the co-operative user experience between the user and the system

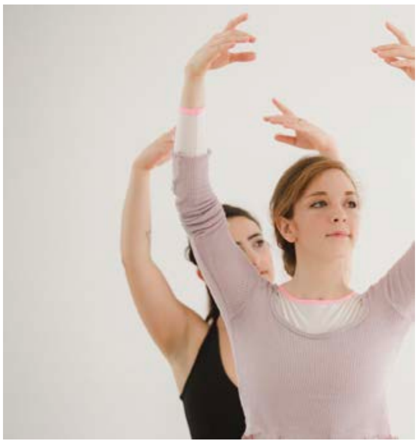
I discovered through the evaluation of three case studies that reaching partnership is a transitional journey for the user. To illustrate this, I will use the pictures below, where the dancer in pink is the user and the dancer in black is the system. The user and the system begin with a ...

Conflicting user experience, where the user does not know the reason for the system to act, does not know what to do while the system acts, and beyond that the experience of the system acting puts the user momentarily in the passenger seat, which is an alien feeling for the user. Through practice, the user begins to build experience in relation to what the system's abilities can afford them.

'I did not understand why it was slowing down, it was unpredictable'.

Fiddly user experience, where the user is learning about when the system acts and through this practice the user and the system define what each is responsible for through acting on one another — as if mapping their sensing abilities as dance moves to perform a choreography. The user experiments with letting go of control momentarily when the system acts, resulting in loss of bodily control over the system.

'I pedalled less to understand it, it reminded me of learning to dance'.



Co-operative user experience, where the user is comfortable letting go of control and fluidly adjusts to the system acting. The user and the system work together to build up each other's abilities and the user reaps the benefits of the partnership.

'I cycle better, more effectively, you're sort of balancing all those skills, it's like your buddy'.

In the case study of Ari the eBike (Chapter 5), I offer a suite of design tactics specifically around facilitating human–system co-operative experiences in an integrated exertion context.

Letting go of control when the system acts

Letting go of control for users takes practice, as traditionally interactive systems did not act on the experience. As such, HCI practitioners need to consider this adjustment curve when seeking to design integrated exertion systems, especially in the quadrant integrated exertion systems *as partners*.

To support users in adjusting to the system acting, I derive the following three design tactics through my case studies that HCI practitioners can apply in practice: (1) Support the rider's autonomy to overwrite the system's actions if they need to, offering a safety net and supporting the user in letting go of control gradually on their own terms. (2) Consider the associated emotions elicited from the user when the integrated exertion system acts in the experience and focus on eliciting emotions with positive valence like joy and delight as these can afford the user an opportunity to develop trust (Dunn & Schweitzer, 2005). (3) Consider the ways in which the integrated exertion system can communicate to the user to gain their trust, because communication enhances co-operation (Wuertz et al., 2018) as it links meaning and action (Donnellon et al., 1986). This can facilitate user–system co-operation to assist the user to develop confidence in their skills and work together with the system in harmony.

Designing the system’s acting to support the user to maintain bodily control over the system

I have studied two approaches that maintained the user’s bodily control over the system: in the *instrumental* section this was Ari whispering in the rider’s ear 'slow down a little'. This message was triggered when the rider was going too fast to be able get the next light on green and the rider could action this instrumental information in order to reach the next light when it was green. In the *supplemental* section this was Ava with automatic hazard lights that turned on when the user was standing up and resuming riding to increase the user’s visibility to nearby pedestrians, vehicles and other bikes, and this was supplemental to the rider while they were cycling.

An important consideration in designing integrated exertion systems is that the system can have more than one way to act on the experience. For example, Ari acted in two ways, increasing engine support to extend the user’s physical ability to go faster and causing momentary loss of bodily control — and whispering in the rider’s ear to facilitate sense-making and benefiting the rider to regulate their speed, while allowing the rider to maintain bodily control over the system. The interplay of these modes of action offered the rider a profile of the system and taught them through practice what the system was responsible for in order for the user to adjust and determine how to use their abilities to better work with the system.

To support users in benefiting from and also enjoying the system’s assistance, I derive the following three design tactics through my case studies that HCI practitioners can apply in practice: (1) The system can use brief contextual cues (such as the 'slow down a little' message while cycling) that the user can easily understand and action – this will reduce operational complexity for ad hoc execution. (2) HCI practitioners can draw from human–animal co-operation literature which has focused on questions such as: 'When to co-operate?', 'With whom to co-operate?', 'What to do in co-operative interactions?' and 'How much to contribute to co-operation?' (McAuliffe & Thornton, 2015). Through these questions, HCI practitioners can form a contextual understanding of the user experience towards designing the interventions that the system can offer to support the user while the user maintains control over the system. (3) HCI practitioners can facilitate make-believe moments by amplifying the user’s sensations. For example, in the case of Ava, while the rider was leaning forward to accelerate, the system also played a turbo sound. This amplified the sensation of acceleration and led to a 'superpower-like experience' where the extra physical ability support felt as though it came from the rider’s body.

Summary of design tactics for designing integrated exertion

Each of the case studies investigated a different form of integration with the exerting body and resulted in detailed themes and design tactics to explore the design space that integrated exertion offers. Through these case studies, recurring themes and design tactics became more apparent and in this section I present a summary of the recurring design tactics. I offer this summary in Table 16 as an overview and invite HCI practitioners to read the case studies for in-depth descriptions of the themes and design tactics within each case study chapter.

Table 16: Recurrent design tactics throughout the three Case Studies.

Recurrent tactics and description	**Case study examples**		
	Ava, Chapter 4	Ari, Chapter 5	Ena, Chapter 6
Shared control *Fine-tune the degree of control the user has over the system by exploring different data that informs when the system acts in the experience*	Where movement data affords the user a high degree of control over the system acting in the experience	Where contextual data affords the user a low degree of control over the system acting in the experience	Where physiological data affords the user a medium degree of control over the system acting in the experience
Acting in real time *Ensure the system acts in real time, in order for the system to be experienced as part of the user's body as a partner and as a symbiotic agent*	The system acts in real time to synchronously move with the user's body to facilitate the user to experience the system as part of their body	The system acts in real time by building from the context of the situation to complement the sensing abilities of the user during the experience	The system acts in real time by reading from the physiological signal of the user to control the system, gaining access to the user's pre-attentive state to support the experience
Extended ability *Explore extending the user's physical and cognitive abilities (sense-making and perception) in different combinations to design integrated exertion experiences*	Where the system extends the user's physical ability, such as by enabling them to go faster, and allows the user to control the system with their body movement rather than using buttons in order for the user to embody the extra strength	Where the system extends the user's physical ability and their cognitive ability to gain increased sense-making in relation to the activity, in order to invite the user to fluidly adjust their actions to work in a partnership with the system	Where the system extends the user's physical ability and their cognitive ability to gain increased perception in relation to previously difficult to perceive or imperceptible information to help the user to 'tune in' and expand their perceptual awareness

Trusting the system *Consider the different tactics to build up the user's trust of the system to facilitate integration*	Where the user has overriding control over the system in order to let the user gradually adjust to the system acting in the experience and build an understanding of how the system works	Where the system turns the interpreted data into ad hoc cues that the user can make sense of in order to turn the cues into actions to benefit from and over time build trust in the system	When the system acts on the experience and focuses on eliciting from the user emotions with positive valence like joy and delight, as these can afford the user an opportunity to develop trust
Extended corporeal awareness *Consider the user's extended corporeal awareness as a design resource that the system can alter to facilitate different integrated exertion experiences*	Where the user's corporeal awareness remains extended to include the system, when the user embodies the control of extra engine support	Where the system acts on the experience by using contextual data and reveals itself out of the user's extended corporeal awareness, drawing a division between the user and the system, strengthening the experience of working as a partner with the system	Where the system acts on the experience by using physiological data and the experience of the extended corporeal awareness can be strengthened by facilitating a kinetic feedback loop between the user's physiological data as a controller of the system

Summary

In this chapter I presented the framework for designing integrated exertion, informed by the three case studies. The framework with its quadrants, experiences, and dimensions contribute design knowledge to HCI practitioners in designing integrated exertion experiences.

In the framework I present the quadrants and twelve user experiences. In the upper part of the framework, the resulting user experiences are linked to the user's agency over the data and each data type can yield a different user experience: movement data (high user agency), physiological data (some user agency), and contextual data (no user agency). The data serves as input to the integration system, from which the system acts and causes the user to experience momentary loss of bodily control over the system, resulting in integrated exertion systems as partners and integrated exertion systems as thrillers.

In the lower part of the framework, I found that the user's agency over the data in relation to the resulting user experience does not depend on a specific data type. This means that systems that use different data types can be categorised within the same quadrant (e.g, instrumental, encouraging, supplemental, disruptive, discouraging, distracting). The reason for this is that when systems in the lower part of the framework act, they are designed to support the user in maintenance of bodily control over the system, resulting in integrated exertion systems as assistants and integrated exertion systems as detractors.

In the next chapter I conclude the thesis and offer ideas for future work.

CHAPTER 8

Conclusion

Integrated exertion futures.

CHAPTER 8 – Conclusion

Through this work I aimed to answer the research question:

How do we design integrated exertion experiences?

Using the three case studies and the framework to synthesise the learnings, I have answered the research question, resulting in theoretical and practical guidance to design integrated exertion experiences.

Research objectives

Previously, in the introduction I presented three research objectives that would guide my research to answer the research question. In this section, I describe how I have addressed these objectives.

1. Understand the role of integrated exertion in supporting the exerting body.

I studied exertion and human–computer integration literature, from which I identified a gap in knowledge for designing integrated exertion experiences. Through this literature review, I learned that technology that focuses on supporting the exerting body can offer various forms of support. For example, by drawing from human–computer interaction in an exertion context, I learned that works in this area focus on designing systems that afford users to experience their body as play in the physical world without being constrained by screens (Mueller, 2017; Mueller, 2020). By drawing from human–computer augmentation, I learned that works in this area focus on augmenting the user's abilities through a tight human–system coupling (Kunze et al., 2017; Schmidt, 2017a). By drawing from human–computer integration, I learned that works in this area focus on the user and the system working in a partnership to accomplish the user’s goals (Farooq & Grudin, 2016; Farooq et al., 2017; Rekimoto, 2019; Mueller, 2020).

Each of these forms of bodily support inspired my exploration to envision that the system could afford the user to experience their body as play in the physical world, the system could augment the user’s abilities, and the system could work in a partnership with the user. However, limited design knowledge was available to guide this exploration towards creating integrated exertion experiences. Through the case studies, I explored different data types as means to integrate the exerting body, revealing details about the different user experiences which are distilled into the framework to make this knowledge accessible to HCI practitioners. Besides the case studies and the design tactics, my framework offers the first practical guide around how the user's agency over the data has user experience implications in the design of integrated exertion systems that can act during the experience and cause the user to momentarily lose bodily control over the system.

2. Explore the applications that integrated exertion offers as a design space.

I explored the integrated exertion design space by building, studying and analysing three case studies, each of which iteratively informed the design of the next.

From Case Study 1, I learned that integrated exertion systems can be designed to allow the user to have superpower-like experiences – one way to do so is when the integrated exertion system draws from the user's movement data to act synchronously with the user, facilitating the user to feel as if the extra physical ability support comes from their body. Furthermore, using sound to amplify the user's sensations can also contribute to their perception of having superpowers and offer make-believe moments, as I showed in case study of Ava (Chapter 4) with the use of the turbo sound that was triggered when the user leaned forward to control the eBike's engine support (Andres et al., 2018).

The idea of designing integrated exertion systems that can afford users a superpower-like experience can be beneficial in various domains, such as playful interactive experiences for entertainment, 'superhuman' sports to afford athletes superhuman experiences and movement rehabilitation to alter patients' mindset on progress for the better (Kunze et al., 2017; Tabor et al., 2016; Veneman et al., 2007).

From Case Study 2, I learned that integrated exertion systems can be designed to work in a partnership with humans – one way to do so is when the integrated exertion system draws from contextual data around the user's body, such as traffic lights data. From this data, the integrated exertion system acts in the experience to extend the user's physical abilities, for example by increasing engine support. The system can also extend the user's cognitive abilities by offering increased sense-making instrumental for the user to act on during the experience towards achieving their goal. In case study of Ari (Chapter 5), I showed that the integrated exertion system can be designed to work in a partnership with the user, such as when Ari assisted the user by increasing engine support to catch the next light on green (Andres et al., 2019).

The idea of designing integrated exertion systems that work in a partnership with users can offer many applications, from instrumental, such as helping commuters cycle from A to B more effectively, helping emergency response personnel on the ground where the human and the system work in partnership to complete rescue operations, and also for playful experiences, where the system complements the user's physical effort, such as allowing less able users to cycle alongside able users by complementing physical effort to afford the proximity to enable a social experience.

From Case Study 3, I learned that integrated exertion systems can be designed to work in a symbiotic relationship with humans – one way to do so is when the integrated exertion system draws from the user's physiological data, such as neurological activity via EEG, to determine changes in the user's field of view. From this data, the integrated exertion system acts in the experience to extend the user's physical abilities, for example by increasing engine support when the neural activity corresponds to the user being peripherally aware. This increased engine support serves as a feedback mechanism that extends the user's cognitive abilities by supporting increased perceptual awareness about the user reaching a state of peripheral awareness. Offering the user the experience of having an extra sense that they can control with some practice as I showed in the case study of Ena (Chapter 6) (Andres et al., 2020).

The idea of designing integrated exertion systems that work in a symbiotic relationship with users can offer a way for users to developing practice to be more aware of, and partially control, their physiological signals to integrate with the integrated exertion system.

3. Create a theoretical design framework.

The three case studies served as research vehicles to explore the research question and each case study led to a publication at a top-tier conference. The feedback received for each publication and the learnings from each case study led to the first iteration of the framework. Thereafter, I iterated on the framework with the assistance of my supervisors and colleagues from the lab.

The publications, the thesis and the resulting framework offer HCI practitioners a first of its kind opportunity to create integrated exertion experiences via the documentation and study of three integrated exertion case studies that resulted in themes and design tactics. My thesis also reports on twelve different user experiences, including details around the impact on the user experience in relation to the user's agency over the data.

My intention with this framework is to discover and explain the design space that integrated exertion offers in order to support HCI practitioners to design integrated exertion experiences.

Research contributions

I make the following contributions with this work:

1. My research contributes design knowledge around how to design and study integrated exertion systems. Each case study offers a different integration mechanism with the exerting body, including implementation details, study results and qualitative details around the user's experience, synthesised in the form of themes and practical design tactics.

2. This research contributes to design knowledge through the creation of a conceptual understanding of the role that integrated exertion experiences can offer to body-based experiences in HCI.

3. My research efforts have led to the creation of the framework for designing integrated exertion. Through the case studies and the qualitative analysis of the user experience, I have created the first integrated exertion framework to offer design knowledge around how to create integrated exertion experiences.

Limitations

I acknowledge various limitations to my work around the case studies. Additional insights could have been derived if participants had had my prototypes for longer, the prototypes had been studied in different traffic conditions and lighting conditions, participants had cycled for longer distances and also if I had had more participants. My recruitment criteria were designed to target a diverse range of participants across age, gender and cycling experience. I recognise that my systems were evaluated with what are considered healthy individuals. In the future I would like to explore how integrated exertion systems can complement different bodies and neuro-diverse individuals to afford integrated exertion experiences. This exploration may offer more user experience insights to enrich the framework.

My work only uses electric bikes, as they allow the user to input physical effort and the eBike can be easily modify to act on data. What if other electric vehicle systems, that also afford the user the opportunity to exert physical effort and can be easily modified, were used to study integrated exertion experiences? Could this offer new integrated exertion experiences as it may use other parts of the exerting body? And also, what if integrated exertion systems were explored in other environments, like mountain biking, paragliding and aquatic experiences?

In my three case studies, I selected the data type and designed how the system should respond. This design-oriented approach did not support participants in choosing which data type or design how the system acted on the experience.

Future work

I now discuss potential opportunities for future work.

Exploring integrated exertion with alternative bodies

I highlighted in the limitations section that my work has focused on what are considered healthy individuals. Future work could focus on diverse bodies or neuro-diverse individuals with the aim of tailoring integrated exertion experiences.

Exploring integrated exertion with other interactive systems

I acknowledge that my work focuses on eBikes and that future work could explore other mobility platforms, including Segways, eSkates, eWheelchairs, and exoskeletons to validate the framework further. These systems appear to be suitable to design integrated exertion systems as they afford the user whole-body interaction, they allow the user to exert, and they come with an electric engine that could be modified to facilitate an integration with the exerting body.

Exploring integrated exertion with 'exerting cyborg bodies'

I presented in the related work section various forms of bodily integration, one of which was referred to as transhumanism and cyborgs. My work has focused on what are considered non-cyborgs, in other words, humans. Future integrated exertion experiences could study the 'exerting cyborg body' and how the the data they have access to could be used alongside integration systems to further the vision of integrated exertion into exciting new ideas. This will further the possibilities of offering integrated exertion experiences to cyborgs of all shapes, sizes and abilities.

Exploring integrated exertion in different environments

All the prototypes were evaluated in the same environment. Future work could focus on designing integrated exertion systems for other environments such as mountain biking, aquatic and air-based experiences to understand the limitations of the exerting body in these environments, and consider how integrated exertion systems could be designed to integrate with the exerting body to support the user.

Exploring integrated exertion using different data and collection approaches

I only explored three different data types (movement, contextual and physiological data), as such, I have only begun exploring the possibilities in terms of data types and collection approaches to experiment with creating integrated exertion experiences. In future work, a possible new data type to use is around the position of other bodies in relation to the exerting body; for example, considering the social experience that occurs when other bodies join the exertion experience. In the section below, I provide more details focusing on the proximity of other bodies.

Proxemics data to facilitate integrated exertion

In personal, social and public situations, the proximity of other bodies to the user's body differs and this results in different experiences (Mueller & Isbister, 2014; Mueller et al., 2014). Interestingly, this proximity can offer a new data type from which integrated exertion systems can draw. For example, a crowd's proximity and their cheering could serve as a data type to increase engine support in a system to support the user physically. The proximity of other bodies around the user's body during the experience, whether for instrumental or play purposes, could serve as a rich data type to explore designing integrated exertion experiences in various domains.

Evaluating and comparing the performance of integrated exertion systems via quantitative metrics

A follow-up study with each of the integration systems presented in my work could focus on applying a quantitative perspective to measure and compare interaction mechanisms.

Validating the framework

In this thesis I have presented a framework for designing integrated exertion, informed by three cases studies. Through the creation of the framework, I consulted with three HCI experts outside of my research group in order to iterate and enrich the framework. The next step in validating the framework will be to hold a workshop at a top-tier conference to invite various HCI practitioners from multiple domains to explore the framework's utility to analyse current experiences and workshop new experiences. The results from this workshop will be summarised in an article for future publication, resulting in further validation of the framework.

Beyond 'integration' – 'fusion' of our bodies with technology

In this thesis I have explored human–computer integration in an exertion context, in this exploration, the three case studies helped me to begin studying different forms of integrating the exerting body with technology. This deepened my thinking on this subject and enabled me to reflect on future opportunities when it comes to using technology to support the exerting body. As such, with the illustrations below I share a potential future concept where we may begin to 'fuse' our bodies with technology (Figure 40).

Towards *fusing* our bodies with technology

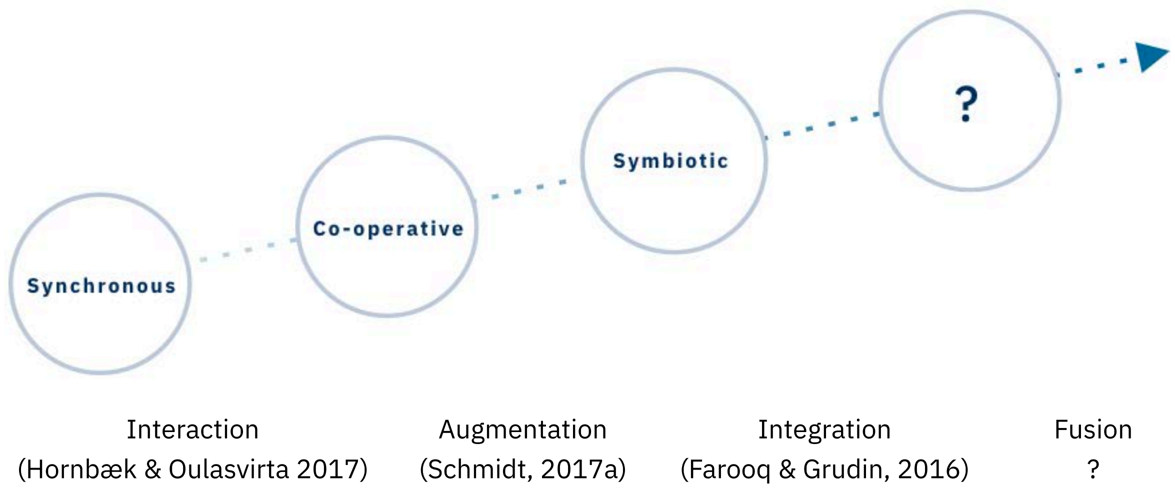
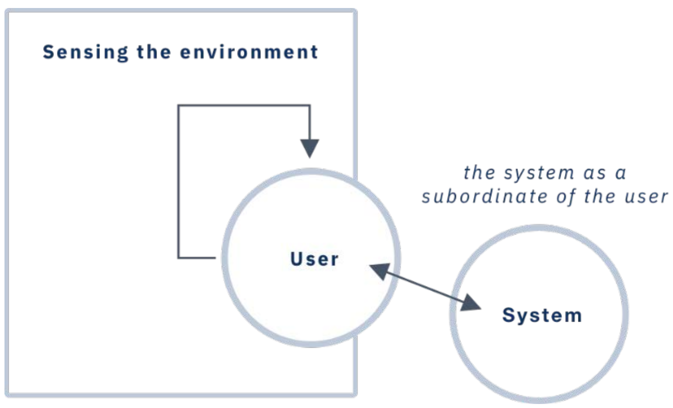
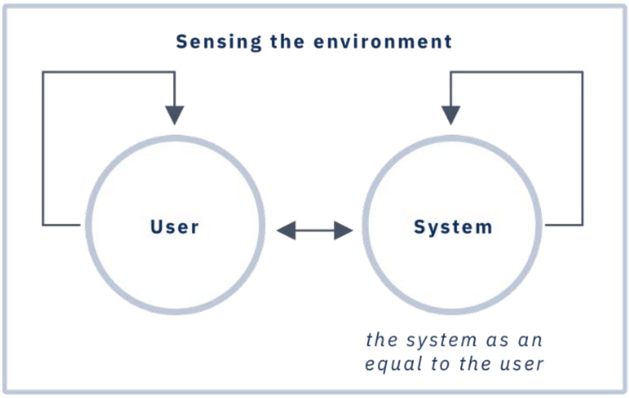


Figure 40. The *interaction–augmentation–integration* continuum towards a future of 'fusion' as the next frontier in HCI.

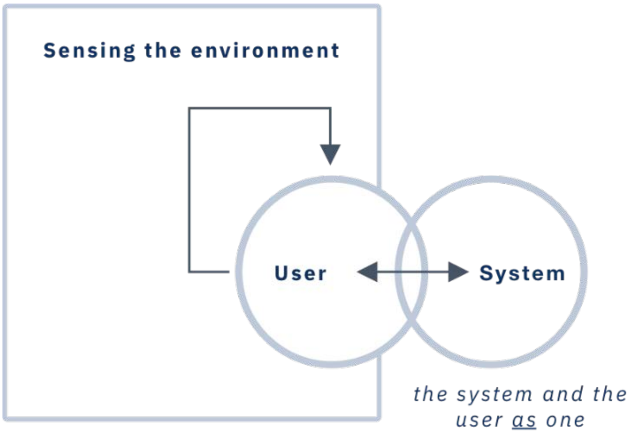
Figure 40 shows the placement of the three case studies in an *interaction–augmentation–integration continuum*, hinting at the progression to fusion where the user and the system become one. To reflect on this vision, in the following illustrations I break down the different integrated exertion experiences I have discovered.



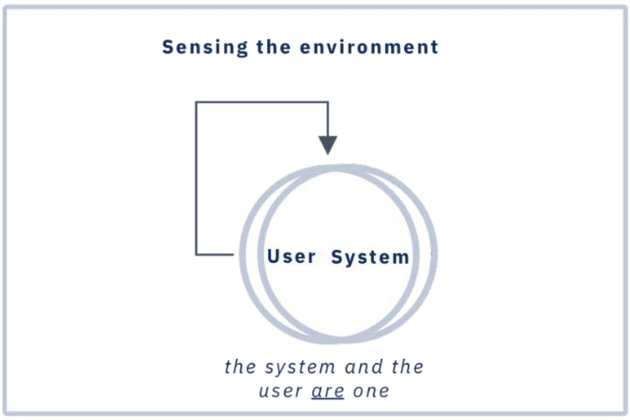
The first integrated exertion experience I discovered was the **synchronous-like** experience, where the system moves synchronously with the user while it remains a subordinate of the user.



The second integrated exertion experience I discovered was the **co-operative-like** experience, where the user and the system work as equal partners.



The third integrated exertion experience I discovered was the **symbiotic-like** experience, where the user and the system begin to work as one system. However, they remain separate agents.



Finally, this trajectory signalled the next step after integration into **fusion-like** experiences, where the user and the system go from *working as one* to *becoming one* operating agent.

In designing for each of the different integrated exertion experiences, I learned that HCI practitioners need to be aware of the learning curve when offering this technology to users, as we cannot simply expect users to reach the end state of integration from the start. Through the case studies, I observed that users begin interacting with the system to explore how it responds. Then they progress through practice to an augmentation stage where they realise their abilities can be augmented. This is followed by the user and the system working in a partnership to reach integration. I see that fusion could be the next long-term research vision and it may offer similar challenges as users grasp what they can do as one agent with the system; this in turn may require the user to transition from interaction–augmentation–integration to fusion.

Closing remarks

Integrated exertion is an emerging design space in HCI that offers applications across many domains and promotes the benefits and joys of being physically active. Through my case studies and framework, I have begun to uncover this design space to contribute design knowledge around how to design integrated exertion experiences and document the user experiences that it can afford so far. These findings are targeted at HCI practitioners interested in designing for the exerting body that is integrated with technology. A considerable amount of effort was required with each case study from conceptualising the idea, building and evaluating the system to publishing each case study.

Through my case studies, I participated in the vision that human–computer integration offers with a focus on the exerting body. In this time, I experimented with various data types to bring this vision to life. This idea of designing technology to integrate with the user's body is not new. Haraway's Cyborg Manifesto (1990), Licklider's Human–Computer Symbiosis (1960), and Engelbart's Augmenting Human Intellect (1962) are touchstone critiques that reflect on how technology could integrate with the human to extend their abilities. These works have inspired my thinking, and to promote this vision, we need to continue working with adjacent communities that have deep expertise in live sciences so that we can work towards fusing our biology with technology. This will raise ethical considerations around the narrative of our future bodies, and it will require reflection about the impacts of the technology we design for beyond our users. To continue charting this exciting path forward, with the presented design tactics and the Designing Integrated Exertion Experiences Framework I contribute to further our understanding to design exertion experiences through a human–computer integration approach to extend the user's abilities and enable engaging experiences.

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