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Intuitive balance-based mobility interfaces

A framework for understanding balance as input in personal mobility devices

Aleksander Rem - Master thesis - November 2015

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Aleksander Rem, Oslo

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Abstract

This thesis examines how balance as input is used as a modality when controlling a personal mobility device. Through a user-centered design approach, we designed and built a fully functional mobility device prototype that uses balance as its only form of user input. We used an online survey for gathering needs and requirements, and created several design concepts and paper sketches through a focus group and design workshop.

A balance controlled electric skateboard was chosen for further development, and iterated through paper prototyping. Two functional high-fidelity prototypes were constructed and tested in a formative and summative usability test with potential users. The prototypes were evaluated through a theoretical framework based on six aspects related to balance as input, which are: intuition, learnability, feedback, reusability, affordance and user experience (UX).

The results showed that most of the participants found the final prototype intuitive. They showed progress during the test which indicates that a learning process occurred. The prototype gave the participants enough postural feedback, and those with a previous skateboard experience were able to use it when testing the electric skateboard, which indicates reusability. Even those that did not have previous experience were able to control the prototype after simple instructions, and every participant expressed how much fun they had using balance to control the prototype.

To conclude, we have showed through our study that it is possible to use balance to control a personal mobility device in an intuitive way, and that the framework we proposed is a useful tool when evaluating balance as input.

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1 Introduction

This thesis investigates how balance and postural control can be used as an input modality. Specifically, we explore balance as the only form of user input in the control of a personal mobility device (PMD). We apply a User Centered-Design (UCD) approach in order to design and build a prototype according to user needs, and present a theoretical framework designed to evaluate if and how balance can be used as an intuitive way to interact with the device. The framework is based on phenomenology and the theory of embodiment and it employs six aspects related to balance as input: *intuition*, *learnability*, *feedback*, *reusability*, *affordance* and *user experience* (UX). A prototype of a PMD with a balance-only interface is designed, built, and evaluated in a usability test. We apply the six aspects from the framework both as guidance in the design process and in the evaluation. The goal is to gain a better understanding of what role balance plays in the users' interaction with this type of user interface.

1.1 Research question

The overarching goal of this thesis is to investigate the perceived intuitiveness of balance based interfaces in PMDs in order to identify opportunities for improving the user interface of such devices. This thesis' main research question is as follows:

> *Can balance alone be used to control a personal mobility device in an intuitive way?*

To best answer this question, phenomena related to using balance as input will be explored in detail, including the learnability, feedback, affordance and user experience of such interfaces. Additionally, the perceived intuitiveness will be of particular interest, according to the research question. These phenomena will be described in the theoretical framework.

The research question has been further divided into a set of sub-questions that aim to explore the question from multiple angles. These are:

- Is it possible to design for intuition?
- Is balance alone considered a viable interaction approach for the purpose of mobility?
- Is a theoretical framework a helpful tool for evaluating this research question?

1.2 Motivation

The motivation for this thesis is threefold. Below we present the motivation for studying embodied human-computer interaction, the motivation for relying on intuition as the main benchmark of determining the success of the interface, and the motivation for choosing personal mobility devices as the technological area and use context. Our motivation for choosing balance as the input modality consists of a more technical explanation and is therefore outlined in Chapter 2 Background instead.

1.2.1 Embodied interaction

Embodied interaction starts with the realization that technology is more than a distraction away from the real world. It should incorporate itself as a natural extension of it, and be as present, participating and embedded in the world as we are (Dourish 2001a). Today, graphical user interfaces on glowing screens of all sizes are all around us. However, computers are not restricted to glass rectangles, and some might argue that recent trends point towards a stagnation of innovation of such interfaces. Pretty pixels are old news, and we are now much more interested in what technology can add of real value in our daily lives. Embodiment, as defined by Dourish (2001b), is a *"presence and participation in the world, real-time and real-space, here and now", and* it is by now a well-established concept within both Human-Computer Interaction and Interaction Design (Loke et al. 2006). With this definition, physical objects are certainly embodied, but so are all of human actions (Loke et al. 2006). In short, embodied interaction can be classified of an umbrella term describing technology that is closer to human experience, thus we consider embodiment a much more exiting path to an engaging and inviting user experience and with a large untapped potential for innovation.

1.2.2 Intuition

The term *intuitive* is often used quite broadly in relation to technology, especially as a kind of buzzword in marketing, but also in our everyday descriptions of technology (O'Brien et al. 2008; Loeffler et al. 2013). Often, the term is used almost interchangeably with *easy to use,* arguably undermining the true meaning of the term. Currently, HCI guidelines provide limited methods for designers to facilitate intuitive interaction beyond ease of use (O'Brien et al. 2008), and because of this, a more clearly defined boundary between intuition and ease of use is needed to separate the terms. Some researchers such as Jef Raskin have argued that easy to use interfaces are often easy because of the users exposure to previous similar systems, and thus '*familiar'* is a better term (Raskin 1994). He demonstrates this by showing that even the use of a computer mouse is not self-explanatory to someone who has only been exposed to a joystick. Based on this description, aiming for intuition could lead designers away from new and innovative forms of interaction and towards the familiar and common that people already know (Raskin 1994).

1.2.3 Personal mobility devices

The importance of sustainable urban transport is an increasing concern, and perhaps the most common approach to sustainability is manifested through the attempt to reduce automobile use in larger cities (Mackett 2012). The socio-economic and environmental implications of cars in cities around the world have caused a paradigm shift in the minds of urban planners over the last years who now envision a city of the future designed around people rather than cars (Moss 2015). Cities like Madrid, Chengdu and Helsinki now limit car infrastructure in exchange for public transit systems, pedestrian and bike roads in certain areas (Peters 2015), and Paris recently banned cars with even or odd ending number plates on certain days of the week for a limited time in 2014 due to record high air pollution (Dowling 2014). City planner Jeff Speck called suburban sprawl[1] *"the worst idea we've have ever had"* and described the automobile as *"[what] was once an instrument of freedom has become a gas-belching, time-wasting and life-threatening prosthetic device"* (2013).

Figure 1.1. Car-free concepts from Chengdu and Sydney (Davies 2012; City of Sydney 2015)

The car-free movement and new urbanism appear to be building up momentum, and are gaining support from environmentalists and the younger generation who want to choose whether or not they want to drive (Moss 2015), but issues that derive from car dependent cities are not limited to air quality and emissions. Congestion, noise and safety also pose major challenges in many areas. Traffic in London moves at the same speed as horse-drawn carriages 100 years ago (Smit 2006), and in Los Angeles commuters spend approximately 95 hours per year stuck in traffic (TomTom 2015). The negative health impacts caused by traffic noise are second only to air pollution, causing cardiovascular disease, cognitive impairment in children, sleep disturbance, tinnitus and annoyances (WHO 2011). Traffic deaths are the leading cause of death among young adults worldwide, and half of all deaths were vulnerable road users (WHO 2013). Some go as far as to say the era of the car is coming to an end, and design critic Stephen Bayley put it this way: *"It's five minutes to midnight for the private car.*

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[1] Suburban sprawl (or urban sprawl) is a term describing low-density, car dependent communities.

It's no longer rational to use cars in cities like London" (Moss 2015). Regardless, the trend is clearly going towards more people focused city planning. Swedish artist Karl Jilg brilliantly demonstrated how little urban space is currently safe for pedestrians in an illustration shown in Figure 1.2. However, if space is to be relocated to pedestrians, what will the sustainable urban mobility of the future look like?

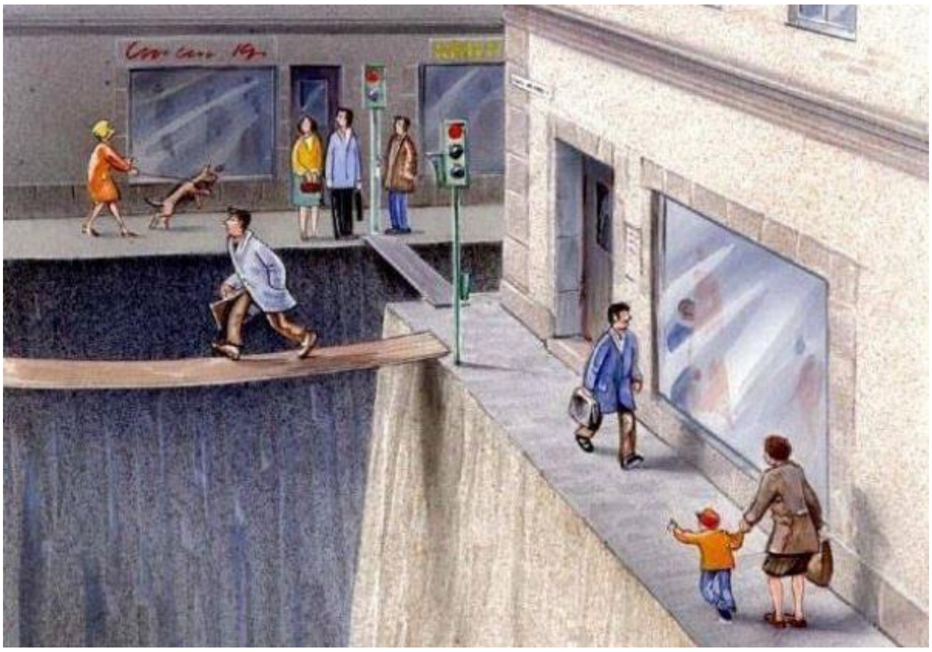


Figure 1.2. Illustration by Swedish artist Karl Jilg commissioned by the Swedish Road Administration

As one might expect, there isn't one single solution that can solve all these problems. Instead, several different modes of transport can help in different situations. The approach that perhaps most people think of in terms of sustainable urban transport is to not actually replace the car, but instead turn the car fleet sustainable through the adoption of zero-emission vehicles like electric cars. Electric cars are undoubtedly part of the city of the future, but they only have the potential to solve problems related to emissions and noise, while still contributing to congestion, safety and health problems from road dust and the inactivity caused by driving.

The other most common proposed solutions are increased focus on walking, cycling, and public transportation, but these have other limitations. With walking, even if the distance is just a single kilometer, most people find it too slow for the fast urban life, and thus is not a realistic travel option for longer distances. Bicycles are great alternatives, but the challenge here is to get people to actually use them instead of cars. Incentives to increase bicycle use has been tried for years and so far we've seen limited success. In Norway, the Norwegian Public Road Administration (NPRA) released a 10-year cycling plan to get the share of bicycle traffic up to 8 % within 2015 (2003). However from 2005 until today this share stood perfectly still at 4.5 % (TØI 2014). Finally, with public transit, in addition to the problem of the last-mile, it is not nearly as comfortable, convenient or reliable as the personal automobile and the routes and timetables poses limitations on when, where and how fast you can travel.

Going from the personal convenience of a car to travelling using human power or relying on public transportation is largely considered a compromise in terms of travel duration, comfort and personal freedom. This is also one of the main criticisms of new urbanism, namely that it undermines the power of the free market and forces an ideology onto society. After all, cars are convenient and most people *want* to drive. This is a valid point that should be taken seriously, and the appropriate response is to make the car alternatives even more appealing than cars, not through external incentives like taxation, but by making the products and services themselves so convenient that they turn into the preferred travel option. The missing piece of the sustainable transport puzzle seems to be travel mode that retains the personal freedom, automation, practicality and door-to-door flexibility of the car without congestion or health problems and this is where personal mobility devices have a huge potential that we are only in recent years beginning to see unfold. Cars will still be necessary in future cities, but we argue that enabling more people to want to not own a car, not for the sake of idealism, but for the sake of convenience, is a goal that is beneficial to every part of society (drivers included), and this is the main motivation for choosing PMDs in this thesis.

1.3 Structure

This thesis is structured as follows:

Chapter 2 - Background offers a brief overview to PMDs, explains what balance is and why it has been chosen as input modality for this thesis, gives a general overview and comparison of some of the different kinds of PMDs that currently exist, and finally outlines the legal situation regarding PMDs in Norway.

Chapter 3 - Literature Review provides an overview of previous HCI research on balance, intuition and UX of embodied interaction.

Chapter 4 - Theory presents the research paradigm as well as a theoretical framework building on embodiment used to evaluate the research question.

Chapter 5 - Method includes the methodological approach and gives an overview of methods used in all four stages of the User-Centered Design (UCD) life-cycle: Needs analysis, design, prototyping and evaluation.

Chapter 6 - Stage 1: Needs analysis presents the results and analysis from all methods used in the first stage of the design life-cycle.

Chapter 7 - *Stage 2: Design* presents the design process that derived from the methods used in the second stage of the design life-cycle.

Chapter 8 - *Stage 3: Implementation* documents the functional prototyping process from start to finish in the third stage of the design life-cycle.

Chapter 9 - *Stage 4: Evaluation* presents the results used to answer the research question. These include all results gathered from the methods of the final evaluation stage.

Chapter 10 Analysis - presents the analysis of the results of the previous chapter used the theoretical framework, and the findings from this inquiry.

Chapter 11 - *Discussion* discusses the results in light of the literature and theory.

Chapter 12 - *Conclusion* summarizes and concludes the thesis, its contribution and presents future work.

2 Background

2.1 What is a personal mobility device?

A personal mobility device (PMD) is a small and lightweight single-person electric vehicle used for personal transport over short distances, typically in an urban environment. There exists many different terms which all describe this class of vehicle, such as personal transportation device, personal electric vehicle, mobility vehicle, personal transporter, or simply rideable. In this thesis, the most widely used term, personal mobility device (PMD) will be used from this point on. The PMD is a fairly recent category of transportation that emerged in the late 1990s (Ulrich 2005) in the form of electric bikes and scooters followed by more specialized designs like the Segway Personal Transporter.

Table 2.1 illustrates where PMDs fit within the transportation landscape. Despite many devices having a specified range of significantly more on a single charge, the typical use case for PMDs is transportation of distances up to 10 km (Ulrich 2005), from now on referred to as *"short distance"*. This places PMDs in the bottom two rows in the table, which means that devices of this category are typically an alternative to public transportation, cars, bikes, and walking.

Table 2.1: Overview of common travel options for various distances

Distance	Travel use case example	Common means of transport
Over 5000 km	Cross-continental	Aircraft
1000 – 5000 km	International	Aircraft, Train
100 – 1000 km	National	Aircraft, Train, Car
10 – 100 km	City, state or county	Public transport, Car
2 – 10 km	City center	Public transport, Car, Bike, PMD
2 km or less	Neighborhood	Car, Bike, PMD, Walking

PMDs offer several advantages over other short distance travel options. Unlike cars or public transportation, a PMD is not restricted to an existing infrastructure like roadways or train tracks. At the same time, it allows you to travel short distances with comparable speed. This is a characteristic it shares with bikes, but using man-powered transportation is not always an option and poses requirements on the rider's physique, travel distance and incline. In addition, man-powered transport can in many situations be unfavorable because of fatigue and sweat, depending on the activity following transport. PMDs therefore offer the speed and infrastructure independence of bikes and other man-powered solutions to a broader demographic and in more situations and thereby provides an increasingly important role in the urban transportation environment.

2.2 What is balance?

Despite the widespread use of the term, human balance lacks a universally accepted definition (Pollock et al. 2000). Oxford dictionary defines balance as *"An even distribution of weight enabling someone or something to remain upright and steady"* (2015). From a mechanical perspective, an object is balanced (in equilibrium) when the net forces acting upon it are zero. In a static situation the object or person remains balanced as long as the line of gravity falls within the base of support (Pollock et al. 2000). If the line of gravity is close to the edge of the base of support, the object will be less stable than if the distance between them is greater. Similarly, increasing the overall base of support (such as, in the case of a human, moving your feet further apart) will also increase stability because the distance between the line of gravity and the edge of the base of support is increased. If the line of gravity moves outside the base of support, the stability is lost and an inanimate object would fall as shown in Figure 2.1. However, humans rely on their balance control system which will trigger a motor response in an attempt to correct and regain balance before falling (Winter 1995; Jancová 2008; Pollock et al. 2000). The system continuously works towards keeping us in balance by monitoring input from multiple sources including vision, touch, motion, equilibrium and spatial orientation, but it can also be impaired through injury, disease or aging (VEDA 2008).

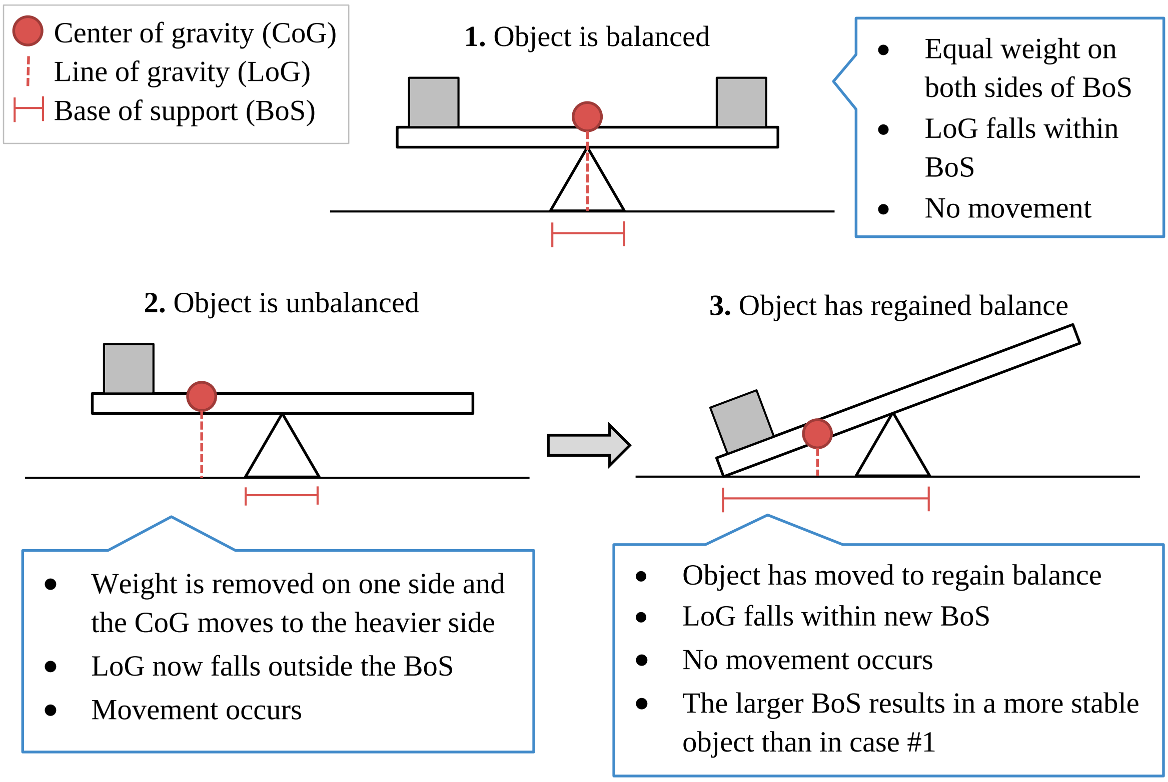


Figure 2.1. Illustration showing the center of gravity, line of gravity and base of support of an object as it loses and regains balance (Derived from Pollock et al. 2000)

In humans, balance is controlled through postural control, which is the ability to control the body's position in space (Sousa et al. 2012). Postural control is generally divided into three main classes of human activity (King et al. 1994):

1. *Maintaining* - Maintenance of posture, such as standing or sitting
2. *Achieving* - Controlled, voluntary movement, such as weight transferring, turning or reaching
3. *Restoring* - The response to external destabilization, such as tripping, slipping or being pushed

In this thesis, human balance and postural control is thus understood as the act of maintaining, archiving and restoring ones line of gravity within ones base of support. Strategies for postural control can be '*predictive*' in anticipation of disturbance to come, '*reactive*' to compensate following unpredicted disturbance, or a combination of the two (Pollock et al. 2000). Additionally, the strategy responses may be categorized as '*fixed-support*' where the line of gravity is moved but base of support remains the same, such as leaning from the ankle or hip, or '*change-in-support*' where the base of support is changed to ensure the line of gravity remains intersected, such as holding on to something or stepping (Pollock et al. 2000).

2.2.1 Why balance?

In this thesis, the inquiry revolves around the use of human balance as the sole form user input to the system for controlling all propulsion-related vehicle functions, including acceleration, breaking and turning. There are several reasons for selecting balance for this task, the most important being that utilizing the riders' balance and postural control actually makes a lot of sense from a physics point of view. Additionally, a physiological reason as well as a more practical convenience related reason will be briefly mentioned below.

The physics reason

First, we should recognize that for a person on an accelerating platform, postural control is already required to prevent falling over. The physics involved is outlined in detail in a paper by Hughes where the forces acted upon a person standing on a wagon being pulled is compared to the leaning interface on the Segway PT (2009). In the example used in the paper, a person is standing on a stationary wagon as shown in Figure 2.2. The normal force of the wagon pushing up, cancels the force of gravity pulling the person down, hence the forces are balanced. Then, the wagon is pulled to the right with an acceleration force, and according to Newton's third law, the rider experiences and equal and opposite reaction force to the left. The result of the wagon forces (Diagram A) which is pushing up (holding the persons weight) and to the right (accelerating) and the riders forces (Diagram B) pushing down (gravitational pull) and to the left (reaction force) creates a torque, or twisting force, because the forces are not acting along the weight of the object (Diagram C).

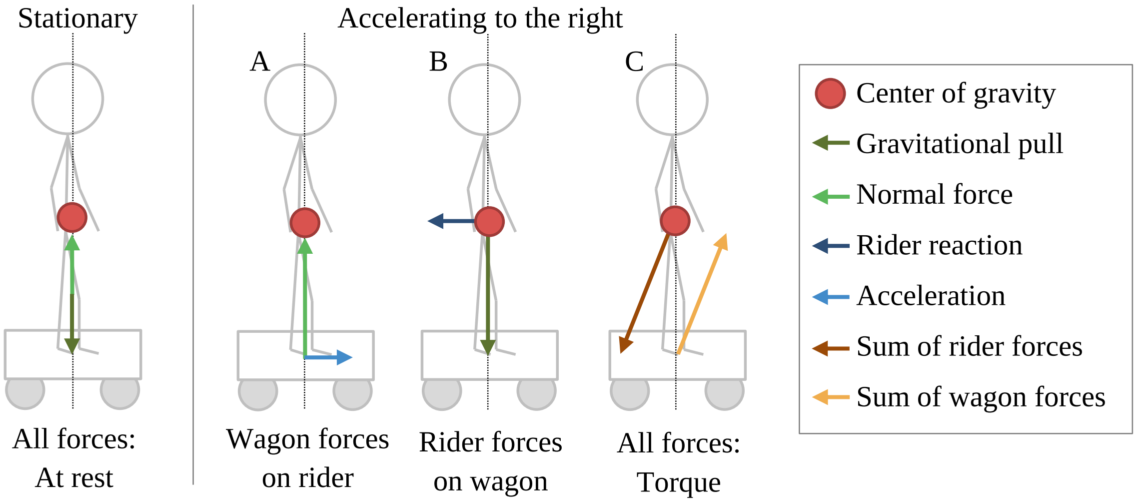
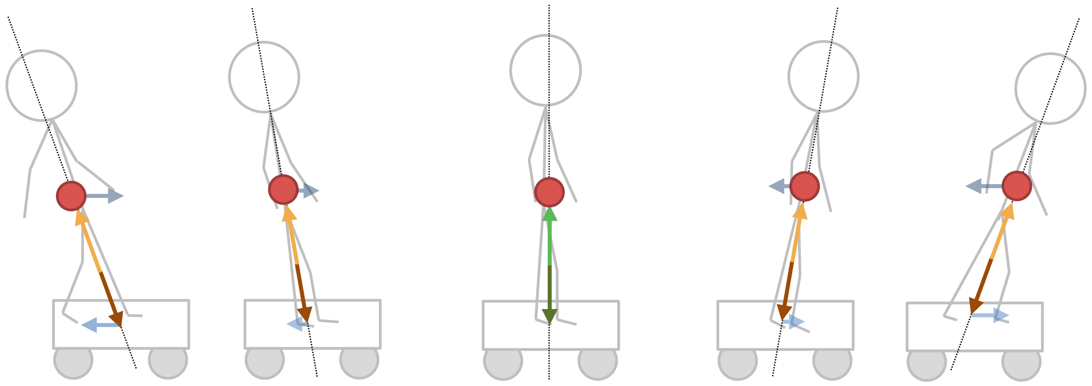


Figure 2.2 Illustration of the forces acted upon a person on a stationary and accelerating wagon (Derived from Hughes 2009)

Due to this torque, an inanimate object in this situation would fall backwards as its head is pushed to the left and its feet are pushed to the right. A person would be notified of this threat to stability by their balance control system and naturally try to restore balance by reactively performing a postural control strategy such as leaning forwards from the ankles and/or stepping to increase the base of support. We commonly feel this effect in our daily lives when standing on a bus or subway that accelerates or breaks and we are required to react to restore our balance, by either leaning to cancel the forces or holding on to something.

In a situation where the acceleration is actually *controlled* by the person's balance, the forces can remain canceled out to create no torque, as long as the rate of acceleration matches the lean angle of the rider. This means that the forces always act along the weight of the rider, which is the case with self-balancing vehicles. In this case, the rider will feel no torque and will not have to readjust their balance, because the vehicle continuously adjusts acceleration rate to match their posture.



Decreasing velocity:
Breaking

Constant velocity:
Stationary / Cruising

Increasing velocity:
Accelerating

Figure 2.3 Illustration showing sum of forces acted upon a person when acceleration rate is controlled by leaning (Derived from Hughes 2009)

However, while self-balancing vehicles only use balance to control the acceleration rate, the same principle could be applied to turning. As utilized by bicycle and motorcycle riders, leaning into a turn allows for turning with a smaller turn radius at higher speeds. This is because the centrifugal force pushing outwards from the turn, together with the riders weight creates a net force going outwards and down from the center of gravity (Fajans 2000; Foale 1997). The equal and opposite forces are friction, which is responsible for the centripetal acceleration, and the normal force pushing up (Normani 2015). By leaning into a turn, the bicycle or motorcycle rider will move the center of gravity inwards causing the outwards and downwards force to travel through the bike and to the base of support, which in this case is where the wheels touch the ground. This effect is also what we feel when sitting in a car that makes a sharp turn and we're pushed to the side of our seats.

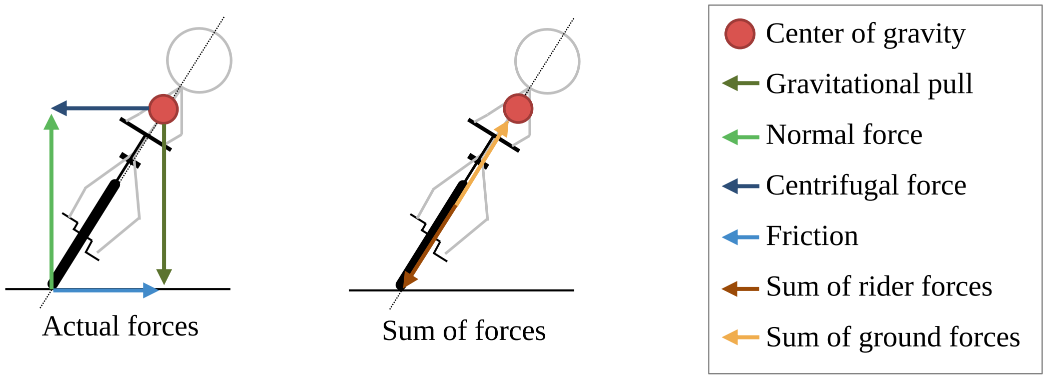


Figure 2.4 Forces acting on a bicycle and rider when balancing the forces by leaning into a turn

In short, using balance for both acceleration rate and turning rate makes sense because they are required by the rider anyway to prevent falling off when the vehicle changes its velocity in any direction. By using this balance as the input, the vehicle can ensure that the forces acted upon the rider remains in balance at all times.

The psychological and practical reason

The second reason for using balance is a psychological reason, and is due to the advantage of the low cognitive load postural control imposes on the rider. Studies have generally found that young people in particular show very little decrease in balance performance during the cognitive conditions (Andersson et al. 2002). Some studies have actually found a slight improvement in balance performance (less sway) during cognitive demanding tasks (Hunter & Hoffman 2001; Kerr et al. 1985). However, even if balance was cognitively demanding, it is already used in many other mobility contexts, such as when walking, running or cycling, and as demonstrated above, is already required to stay balanced on a platform with changing velocity and thus needed in virtually all personal mobility devices, whether they are controlled using balance or not. Vehicles not controlled using balance would therefore require additional cognitive attention to steer the vehicle on top of the postural requirement.

The final reason that will be mentioned briefly is a more practical reason. From the users' point of view, using balance means that users are only using their lower-body to move, just like when walking. This means that hands are kept free to hold or carry objects, whether this is their work laptop, groceries, food or drinks, an umbrella, a shoulder bag or anything else. The bodily freedom from walking is largely retained with a balance-only interface, which is not the case with bikes and other PMDs.

2.3 Comparison of current PMD designs

In order to provide an overview of some of the more common PMD designs, a comparison of currently available PMD products is shown in Table 2.2. The comparison is provided to show some of the differences in attributes between three common form-factors. In an attempt to compare these designs as objectively as possible, the comparison is based only on the statistics of a common mid-range product associated with each form-factor. While there are certainly differences between products within a specific category, the comparison is still useful in determining some of the key differences in attributes like size, weight, and range. A brief description of each of the form factor is presented following the comparison table.

Table 2.2 Comparison of common PMD form-factors

Segway / Self-balancing	E-Bike	Electric scooter
		
Segway i2 Approximately $6,500 Weight: 47.7 kg Road footprint: 48 x 63 cm Battery: Lithium-ion Range: 36 km Speed: 20 km/h	**iZip E3 Dash** Approximately $2,600 Weight: 22.4 kg Road footprint: 172 x 55 cm Battery: 48 volt, 8.7 Ah Lithium-ion Range: 40 to 72.4 km Speed: 32 km/h (pedal assist: 45 km/h)	**Go-Ped ESR750 Li-Ion 16** Approximately $2,400 Weight: 18 kg Road footprint: 122 x 45 cm Battery: 24 volt, 16 Ah Lithium-ion Range: 22.5 km Speed: 32 km/h

2.3.1 Segway

The Segway is perhaps what most people think of when they think of small electric vehicles. Much of its popularity is due to its interesting and unique look and control mechanism. It is a self-balancing vehicle with a platform between the two wheels that the rider stands on while holding on to the handle-bars. Acceleration and breaking is done by leaning forwards and backwards. Turning is done by tilting of the handle-bars and thus it is not exclusively controlled using balance. It is a fairly large and heavy device, so it cannot easily be carried or brought inside buildings. Thus it must be parked outside like with bikes. The handle-bar can on most models be un-mounted so it fits inside the trunk of a car. The 2nd generation devices cost roughly $6,500, placing it in the same price range as a high-end full-size scooter and considerably more than your average PMD. At the same time it should be noted that the popularity of the devices has spawned many look-alikes from various manufactures that tend to be considerably cheaper. The road-footprint is slightly wider than a person standing upright because of the wheels of each side. One of the main advantages of the Segway is its high maneuverability, allowing it to turn on the spot to cut sharp corners and traveling at slower than walking speeds without fear of falling off. Because of this, navigation through crowds can be done fairly easily. This has made it a popular choice in applications where crowded situations can occur like shopping centers, airports, convention centers and police and security applications.

2.3.2 E-bike

E-bikes or Electric bicycles generally look similar to normal bicycles except for the battery-pack, but especially in recent years it has become more and more difficult to distinguish normal bikes from e-bikes as batteries become smaller and are often integrated into the steel-frame. Size-wise e-bikes are about the same as normal bikes and thus require a car mount if the bike is to be transported by car. Foldable e-bikes exist as well however, for making portability easier. Weight-wise they are heavier because of the added battery and motor, but weight, price and range varies heavily among the different models available. The maneuverability of an E-bike is comparable to a normal bike, but the added weight can make traveling at slow speeds or through crowds slightly more difficult. E-bikes typically have a longer range compared to other PMD form-factors and this, coupled with the fact that it must be parked outside buildings means they are best suited for distances in the upper-level of the usual PMD range. Some e-bikes can be used both in pedal-assist mode, where the motor power is added to the riders own pedaling, and twist throttle mode, where acceleration is done exclusively through the motor.

2.3.3 Electric scooter

The term "electric scooter" can both refer to traditional full-size scooters with its combustion engine replaced by an electric motor, as well as the small kick-scooter type with an added motor and sometimes a small seat on a pole connected to the base for added comfort on longer trips. In a PMD context, the term refers to the latter kind and that's what the term "Electric scooter" will refer to from now on. Electric scooters, like E-bikes, come in a wide variety of price ranges, sizes and specifications from many different manufacturers. Many models have cheaper gas-powered counterparts.

2.4 Legal issues

In Norway most PMDs are still illegal to use on public roads. Norway is generally very open to new green technologies, so it begs the question why the government would want to prevent measures contributing to electrification of transportation while also relieve load on the current commute network. In 2009, a politician from the Norwegian Progress Party sent a written question to the government to ask about the reasoning behind the ban on the Segway and other small electric vehicles. In the answer, politician Liv Signe Navarsete replied *"The way we and several other European countries have considered it [...] both the Segway and electrical scooters (go-ped) are, according to their construction, motorized vehicles in the group two-wheeled motorized vehicles. They must therefore meet the technical requirements posed for approval of the vehicle. Most vehicles of this type do not meet the requirements, and are thereby not allowed to be used in Norway."* (Stortinget 2009)

In other words, because there are no laws in place to specifically allow PMDs, these vehicles require registration, insurance, a driver's license and helmet, and must meet the same safety requirements as motorcycles, scooters and other two-wheeled motorized vehicles for them to be legal. Both the Segway and other PMDs are obviously not designed to meet these requirements as their application is probably a lot closer to a bike than to a motorcycle or scooter.

But what about other low-speed motorized vehicles like electric wheelchairs and e-bikes? The law on motorized vehicles actually includes a set of exceptions or "loop holes" to allow these devices on the roads. The law on motorized vehicles applies only to vehicles with a top speed above 10 km/h. This is just slightly above walking speed and it is difficult to see any other reasoning behind this restriction than to specifically allow electric wheelchairs.

Another exception to the law is that it only applies to devices which are fully powered by a motor. In other words it does not apply to devices with pedal-assisted motors, as long as the motor does not assist above 25 km/h and the total power of the motor does not exceed 250 watts. This allows pedal-assist only e-bikes of 250 watt motors or less to be legally classified as human-powered bicycles.

2.4.1 The Segway law

The legal situation changed in June of 2014 (about one third into the writing of this thesis) when the Norwegian government passed a law allowing the use of self-balancing vehicles on sidewalks, bike roads, and roadways with a speed limit of 60 km/h or less, similar to bicycles. It is generally known as *"The Segway law"* because it was put in place to specifically allow the use of the Segway, as evident during the announcement of the law where prime minister Erna Solberg announced that they would *"legalize the Segway"* (Amundsen 2013). The law is somewhat confusingly restricted to only allow the use of one wheeled or two wheeled inherently unstable vehicles that utilize a self-balancing helping system to stay balanced (LovData 1994). The legalization of products on the sole basis of technical implementation is highly unusual, and this means that self-balancing unicycles and other self-balancing two-wheeled vehicles are allowed, but vehicles without self-balancing systems like electric kick scooters are not.

The consultation paper from the hearing sheds some light on the reasoning behind this legal PMD discrimination. According to the paper, the NPRA would prefer a holistic processing to establish regulations for all electric vehicles meant for one person. However, *"Given the short deadline for completion of the hearing that the government has outlined, we find it necessary to restrict our efforts to apply to self-balancing vehicles"* (NPRA 2014, p.2). Later that year the NPRA did indeed initiate an assessment on the legalization of other small electric vehicles (Nordahl 2014), but the result of this assessment has not been published as of July 2015.

3 Literature Review

The literature is split into two chapters: Literature Review in Chapter 3 and Theory in Chapter 4. Chapter 3 includes studies and literature that focuses more on practical application, while Chapter 4 presents the theoretical literature that constitutes the theoretical framework used to analyze the results.

In the literature review presented below, we will look at HCI research within the three main topics of interest to the research question: Balance, intuition, and embodied experiences.

3.1 Balance as input

The use of balance interfaces is a fairly recent concept within HCI and there seems to be little research conducted on the topic so far, usually in relation to virtual environments. We have selected three related works with different approaches on the use of balance interfaces. One comparing balance to a tradition button-based interface, one that compares different feedback setups for a balance interface, and one that investigates more practical approaches to how balance interfaces can be used to complement other types of interaction.

Fikkert et al. (2009) conducted a study comparing the use of lower-body input to traditional hand held game controllers. Balance was used as input to let participants navigate a virtual maze using the Wii Balance Board, a board about the size of a normal body scale able to detect the center of mass of the person standing on it. Their performances were evaluated as they navigated the maze using their lower-body and performed cognitively demanding tasks by pressing specific buttons to open doors with a Wii remote. While using their lower-body to navigate the maze, participants kept their hands free to issue commands with the hand held controller. This was then compared to navigating the same maze using the Wii remote to both move (by tilting the remote) and performing the same cognitive tasks. The authors found that while using the remote to navigate the maze was significantly faster, the balance board was both easier to learn and use and felt more intuitive to the users. In addition, the users strongly indicated that they enjoyed using the balance board to navigate the maze more than the remote. These results indicates that while a balance sensing system may not be as precise as a more traditional button-based interface, it could still be easier to learn and provide a more fun and intuitive user experience.

Wang & Lindeman (2012) conducted a study comparing two modes of balance control; isometric and elastic, with a leaning-based surfboard interface in a 3D virtual environment. They used the isometric Wii Balance Board and the elastic Reebok Core Board, and combined them by mounting the Balance Board on top of the Core Board. They could then switch between the two modes by putting 4 wooden pieces into the core board to support the participants weight and prevent the Core Board from tilting to test balance from the Balance Board only (isometric), or removing the wooden pieces, making the Core Board free to tilt as participants leaned from side to side with the Balance Board detecting their movements on the top (elastic). The system used the Balance Board as a surfboard travel interface where participants were free to surf through the air in all directions in 3D virtual environment similar to the Silver Surfer while collecting as many targets as possible in the given amount of time. The study consisted of three sub-experiments, one testing only vertical/pitch movement, one testing only horizontal/turning movement, and a combined experiment where participants could move both vertically and horizontally. The participants executed each sub-experiment in both isometric and elastic mode and were then asked to answer a questionnaire and rate a set of questions, such as intuitiveness and efficiency on a 6-point Likert scale. They found that participants preferred the tilt board because it was more intuitive, realistic, fun and provided a higher level of presence. However, they found no significant difference in the user performance of the number of targets collected, or the time required to complete the training session. These results suggest that people will prefer an elastic balance system over non-elastic, but that either method will work with no impact on performance.

Haan et al. (2008) demonstrated different scenarios where balance interaction could assist traditional hand-operated input in a virtual reality (VR) setting. They tested the use of a Wii Balance board as an input device in 3 different interaction modes both while sitting and standing.

- 3D rotation control: The balance board was used to rotate objects in three dimensions while keeping hands free to perform other interactions with a mouse and keyboard. The three dimensional rotation was achieved by rotating the x, y and z axis of the object when the user shifted his/hers balance either forwards or backwards, left or right, or applied weight on the toe and heel of the opposite feet respectively.
- Navigation control: In this mode of interaction, the balance board was used to navigate a first-person viewpoint. Leaning forwards or backwards controlled “drive” in either forwards or backwards direction. Leaning left or right controlled the panning or strafing left or right, while pressing the toe and heel of opposing feet controller turning.
- Abstract control: A third interaction mode was tested to control more abstract, application specific input such as switches or one-dimensional input like time or zoom. This effectively “de-coupled” these tasks from the environment so the user no longer had to directly interact with the virtual environment to control it.

In general, the authors found that all three interaction modes worked well, but that not all degrees of freedom could be controlled with the same ease and that ceasing input is not instantaneous due to the delay of the user shifting his or her body weight. Side to side motion in particular was found to be slower and required more effort on the user’s part. The authors partially remedied this by adjusting the threshold and scaling of the signals from the board. The authors concluded, based on their experiences and input from their colleagues that the balance board was effective and easy to use, which suggested that the balance board could easily be used in a wide variety of applications, even outside of VR.

3.2 Intuitive interfaces

Bullinger et al. (2002) presents 3 concepts from their INVITE research project for improving the intuitiveness of human-technology interaction:

- Dynamic visualization: Manipulable information structures, context and focus techniques, and both 2D and 3D immersive information representation.
- Multimodal interaction: Focus on combined gesture and speech input, including translation of texts and special input devices.
- Cooperative exploration: Providing functions for exploring Web content in groups or collaboration with intelligent system agents, working together with the user in a synergistic way.

These interaction paradigms were used in various prototypes and tools presented in the paper that were tested and shown to have performances and efficiency advantages when compared to standard tools. They interpret intuitive interaction as interaction that is more adapt to the human’s natural means of expression, and immediate usability where minimal learning and prior knowledge is required. They argue that designing intuitive interaction must be done through a strong user-centered approach, and that the interaction must be based on the users’ natural or acquired skills and knowledge. They conclude that immersive, real-time simulations are important means of making computer-aided engineering tasks more direct and intuitive.

Nielsen et al. (2004) conducted a study on intuitive and ergonomic gestures. The authors employed a user-centered approach to finding functions and identifying natural gestures for these functions. The gestures were observed and counted for each function and this analysis resulted in a final gesture vocabulary. These gestures were then benchmark tested according to their semantic interpretation, generalization, intuitivity, memory, learning rate and stress. The benchmark was tested in 3 test groups: Engineers, architects, and engineering students. The authors found similar performance in the two engineering groups, but the architect group scored lower when trying to guess which function the gestures represented. Conversely, the architect group scored better on the memory test, when asked to perform the gestures in sequence. The authors conclude that a technology-based approach leads to an awkward gesture vocabulary without intuitive mapping between gesture and function. The resulting gesture vocabulary was found to be easy to use, fast to learn and remember. However, the procedure was rather time-consuming and the scenarios where the gestures are used must be carefully written.

The authors also emphasize the need for user profiles when finding gestures, because the gestures extracted from engineers performed best with engineers.

Hummels et al. (1998) propose a gestural interface for product design that supports the perceptual-motor skills of the designer and the expressive and creative design process. They argue that the limitations and possibilities offered through gestures support intuitive human-computer interfaces in product design. Dividing gestural interfaces into three different approaches: pre-defined symbolic commands, gesticulation and act gestures, they propose act gestures as the most suitable for intuitive interaction. Pre-defined symbolic commands are essentially a '*gestural language'* where each command must be learned, and gesticulation is a more of a communication tool than a natural way to interact with objects. Act gestures on the other hand are suitable for intuition because this approach allows us to afford possibilities and act related to our body and perceptual-motor skills. The authors conducted two experiments: One were participants were asked to show with act gestures and voice how they would design a water bottle, and a wizard-of-oz style experiment where an artist was drawing and showing the objects as the participants designed them using act gestures. The two experiments show that the subjects had different personal styles and that there were only a few inter-personal consistencies. Additionally, the mapping between hand postures and meaning was not one-to-one. They conclude that while a trained artist could recognize the meanings of the gestures, it seems difficult to implement gestures unambiguously in a design application without regarding context and affect.

3.3 UX of embodied interaction

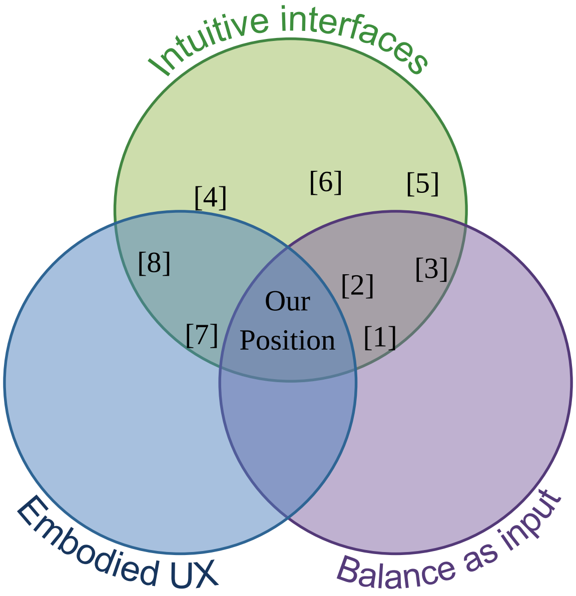
Research on optimizing user experience is often revolved around screens and graphical interfaces, but the rapid development of small integrated processors in the last decade has opened the door for user experience research on embedded computers without any graphical or screen-based interface.

For example, in a study by Moen (2007), the author argues that movement-based interactions should be designed from a non-technical, people-centered point of view in order to create embodied and engaging user experiences. In the paper, he presents the design process and user explorations of a wearable movement-based interaction concept called the BodyBug, which was created to explore full-body movement as interaction modality. Modern and contemporary dance was chosen to obtain a people-centered basis for the interaction design. This was chosen not only because it provides an existing vocabulary of expression, but also because it has a diverse variance in style and individual preferences and because it is concerned with expressing the movement rather than the form. The device was designed based on the results from a field study where the authors observed and interviewed participants attending a course in improvisation and composition based modern dance. The resulting prototype consisted of a small 4x5x6 cm box attached to a thread where the box was able to climb up and down the thread based on the movement of the user. At the end of both sides of the thread was a strap that could be attached to any body part. The authors did not give the participants any set of pre-defined rules to make the BodyBug move and thus the user had to figure out which actions would cause the bug to move. Consequently, the participants performed widely different movements when interacting with the device. Some used big, violent movements, while others stood mostly still trying to figure out what the BodyBug would react to by moving only one body part. Users described it as interesting and encouraging, and several participants came back for another try. From their observations, the authors identified that the success of an embodied user experience relies on having movement-triggers, i.e. motivations for people to move, as well as a social excuse or reason to move, i.e. that these movement patterns are socially and culturally accepted in the context of which the interaction takes place. The social and cultural context therefore defines which movements are appropriate for the interaction. The authors also observed large individual differences in which movements feel comfortable, so having a strict set of rules that must be followed for a successful interaction is likely to limit the number of people who will enjoy the experience. Some of the questions designers should ask themselves are: Should the interaction be highly visible or discrete, or can it be scaled according to the sociocultural context and personal preference?

Another relevant study in this context was conducted by Larssen et al. (2004) exploring movement-based input using a PlayStation2 EyeToy. The authors used two existing frameworks for conceptualizing the interaction: *Sensible, Sensable, Desirable: a Framework for Designing Physical Interfaces* (Benford et al. 2003) and *Making Sense of Sensing Systems: Five Questions for Designers and Researchers* (Bellotti et al. 2002). The participants were first video-taped as they played two different games for the EyeToy, Beat Freak and Kung Foo. They were then interviewed about their experience with the games. The frameworks were used to categorize the movements and actions performed by the participants during play, and look at how movement as input would hold as communication in the interaction. The authors found that both frameworks were valuable tools to aid researchers and designers in understanding the specific challenges that new interaction and input options present. They conclude that when movement is the primary means of interaction, the forms of movement, enabled or constrained by the human body together with the affordances of the technology, need to be a primary focus of design. Additionally, an intuitive and natural interaction through movement relies on appropriate mapping between movement and function.

3.4 Map of related work

In order to situate the study in this thesis in relation to the existing body of literature, an illustration showing the intersections of the three topics and how, according to the thesis author, the related work is positioned within these topics is presented in Figure 3.1. Below is a table of the related work, labeled by number and color-coded categories. While several of the studies presented branch into the other topics, there was an absence of papers where all three of them were intersected, which is where this thesis is positioned. Interestingly, there was also an absence of papers focused on the UX of balance as input (blue and purple in the illustration). This might suggest that studies concerned with the intuitiveness and UX (in particular) of balance interfaces are currently under-researched within the current body of HCI research.



#	Related work	Categories		
[1]	Navigating a Maze with Balance Board and Wiimote (Fikkert et al. 2009)	🟪	🟩	
[2]	Comparing isometric and elastic surfboard interfaces for leaning-based travel in 3D virtual environments (Wang & Lindeman 2012)	🟪	🟩	
[3]	Using the Wii Balance Board as a low-cost VR interaction device(de Haan et al. 2008)	🟪	🟩	
[4]	Intuitive Human-Computer Interaction - Toward a User-Friendly Information Society (Bullinger et al. 2002)		🟩	
[5]	A procedure for developing intuitive and ergonomic gesture interfaces for HCI (Nielsen et al. 2004)		🟩	
[6]	An Intuitive Two-Handed Gestural Interface for Computer Supported Product Design (Hummels et al. 1998)		🟩	
[7]	From Hand-held to Body-worn: Embodied Experiences of the Design and Use of a Wearable Movement-based Interaction Concept (Moen 2007)		🟩	🟦
[8]	Understanding movement as input for interaction–A study of two Eyetoy™ games (Larssen et al. 2004)		🟩	🟦

Figure 3.1 Figure and table of numbered and color-coded related work

4 Theory

As researchers we must recognize that even science is a social construct and is *“as dependent on the beliefs and values of scientists as it is on the strict adherence to abstract methods and measurement”* (Angen 2000, p.386). The notion that research is based on ontological and epistemological assumptions is widely accepted (Gialdino 2011, p.2), and hence it is important to first explain our position on this matter.

4.1 Paradigm, Ontology and Epistemology

A researcher’s position towards ontology and epistemology will have methodological implications for how they approach their research (Gialdino 2011). These positions will typically be explained in relation to the researcher’s paradigm, where the debate is largely divided into proponents of quantitative methods and the positivist paradigm, and the interpretivist paradigm that rely primarily on qualitative methods (Angen 2000). As the topics to be explored in this thesis are related to balance and intuition, the interpretive paradigm has been considered the most appropriate for this study. The interpretive paradigm belongs to relativist ontology that rejects the notion of individuals having direct access to an objective reality, and instead holds the position that realities are multiple and exists only as mental constructs in our minds (Guba 1990, pp.26–27). Relativists thus consider the question of *“how things really are”* to be meaningless because realities are local and specific to each individual, shaped by experience and social factors (Guba 1990, pp.25–27). Epistemologically, intepretivism belongs to a subjectivist position where knowledge is understood as something that is ‘perceived’ (Carson et al. 2001, p.6). They argue that objective knowledge will forever remain unreachable because the interpretations and cultural orientation of a ‘human instrument’ can never be fully separated from the observation (Somekh & Lewin 2005, p.16).

Conversely, the positivist paradigm hold a realist position where a single external reality exists *“out there”*, and is driven by immutable natural laws (Guba 1990; Carson et al. 2001). Realism comes in many variations such as naïve realism, critical realism and historical realism, and these typically differs in the degree to which reality is considered apprehendable (Lincoln & Guba 2000). From a realist position knowledge must be acquired through an objective distance from the world to prevent tainting the truth with our own subjective beliefs (Angen 2000, p.380). This is known as the objectivist epistemological perspective, where the inquirer puts questions directly in nature and observes from a distance as nature provides the answer (Guba 1990, p.19).

The reason we subscribe to the interpretive paradigm is not only because it is difficult to measure the perceived intuitiveness of a balance controlled device through a positivistic lens, but also because understanding the use of the vehicle and its interface is much more important in this context rather than measuring its performance. Further, embodied experiences are highly personal and may be perceived differently from individual to individual due to differences in physical needs and preferences. Thus, the notion of a single objective truth when it comes to embodied interaction experiences is problematic, and an interpretive approach would likely be more insightful.

4.2 Theoretical Foundation: Embodiment

In the next section, we present the theoretical framework which was established to provide the theoretical structure to guide the research. A central point when establishing this framework was that our inquiry was focused on the human body and its capabilities, rather than on the technology. The research question entails that this study is both placed within *movement as input* (balance), as well as *movement as output* (mobility). When it comes to embodied interaction, many researchers have previously employed a phenomenological perspective, such as (Dourish 2001a; Larssen et al. 2004; Klemmer et al. 2006; Moen 2005). We have decided to take a similar approach and base the framework's foundation on the theory of embodiment and phenomenology. The theory of embodiment is a widely discussed philosophical construct during the 20th century where the body plays a central role in understanding cognition and human experience. Embodiment was also an important topic in Merleau-Ponty's *Phenomenology of Perception* (1962) where one of his central points was that since we are embodied subjects – i.e. we perceive the world by living in our bodies, perception must be understood through the body and its capabilities as an always active and embodied constitution of both the body and the mind. This approach to designing for the lived body has been used by an ever increasing number of HCI researchers for a wide variety of a applications, such as movement-based interaction (Moen 2005; Loke et al. 2006; Larssen et al. 2007; Klemmer et al. 2006), context-aware computing (Dourish 2001a; Svanæs 2001) and social interaction (Ludvigsen 2006). These technologies rely on a wide array of sensors such as vision sensors, pressure, motion, proximity, accelerometer, gyro sensors and others (Larssen et al. 2007), but as previously mentioned our focus of inquiry lies on the human body and its capabilities.

4.3 Theoretical Framework

Our theoretical framework is composed around theories and models that are compatible within an embodied and phenomenological sphere. We return to phenomenology in the discussion, but for now let us focus on the three theories that will be applied in the framework:

1. *Tacit knowledge* - A theory describing knowledge that is too complex to be sufficiently taught or explained verbally alone, such as riding a bike.
2. *Dreyfus skill model* - A model describing the different levels humans go through while learning new skills, from beginner to expert level.
3. *Natural User Interface* - A framework for designing user interfaces that reuse existing human skills.

This theoretical framework was used to guide the approach for answering the research question. The framework has a particular focus on embodied skill, learning and intuition, which are concepts that are covered in all three theories. Each of these theories will be presented in more detail below before we will demonstrate how the concepts will be applied in this study. An overview of the framework and the concepts it includes can be seen in Figure 4.1.

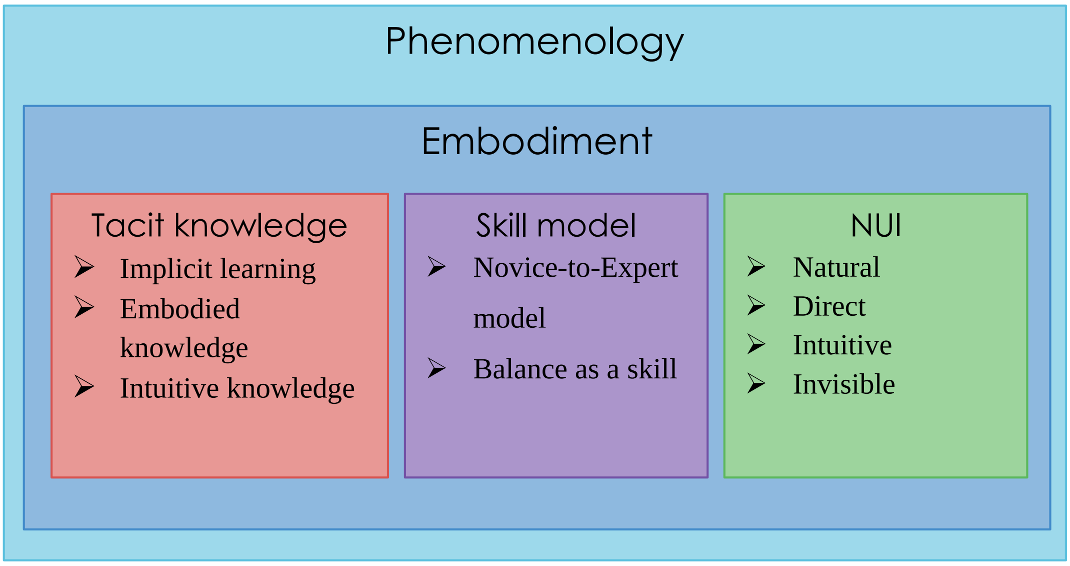


Figure 4.1 Overview of the three components of which our theoretical framework is built

Rather than using these concepts in isolation, we have established a theoretical framework in which we employ a combined understanding of the theories. We argue that these theoretical concepts share many similarities and in combination provide us with a richer understanding of skills and learning.

4.3.1 Tacit Knowledge

The term tacit knowledge was first coined by Michael Polanyi as a kind of personal knowledge that can't easily be transferred verbally from one person to another. Polanyi wrote in his book *The Tacit Dimension* (1966) that *"we know more than we can tell"* to emphasize that not all human knowledge can be formulated explicitly. Put simply, tacit knowledge are the things we know that we can't explain how we know, such as perception, recognition, attention, information retrieval and motor control

(Busch & Richards 2003). However, tacit knowledge is not limited to innate human abilities. Learned skills, routinized actions, the ability to understand people or situations and the unconscious processes that lead to intuitive decision-making are examples of tacit knowledge we acquire and refine over time as human beings (Eraut 2000). This is knowledge that is too complex to be outlined in a book and requires practice in order to be learned. Further, due to the fact that tacit knowledge is usually gained through experience and is difficult to share with others, there will be large individual differences. This is in contrast to explicit knowledge, which can easily be verbally taught or explained, typically in a more formal context such as a teacher-student setting, resulting in each individual having the same or similar understanding of the knowledge.

Aspects of tacit knowledge

Bennet and Bennet (2008) categorize the sources of tacit knowledge into four aspects: embodied, affective, intuitive and spiritual. Each represents different sources of tacit knowledge with a varying level of awareness. Figure 4.2 shows these aspects along with explicit and implicit knowledge. Neither spiritual knowledge, representing a form of higher guidance, moral values and purpose, nor affective knowledge concerned with knowledge of emotions and feelings are particularly relevant for the study. Instead the framework will apply the concepts of intuitive and embodied knowledge, which are both highly relevant concepts for evaluating the intuition of an interaction that revolves around body movements.

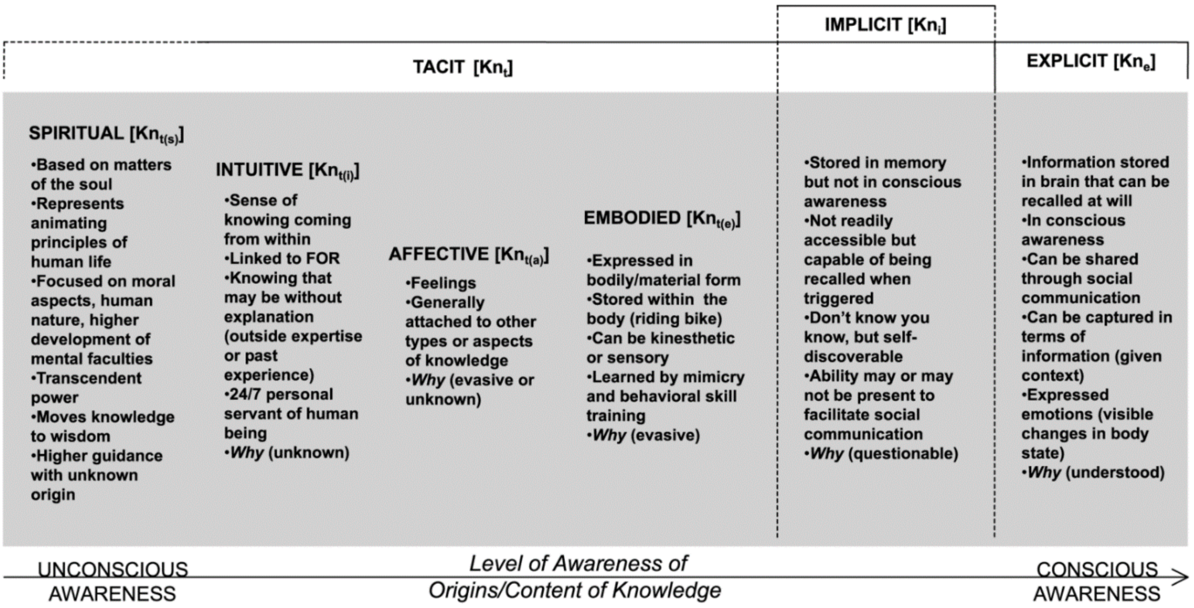


Figure 4.2 Continuum of Awareness of knowledge source/content (Bennet & Bennet 2008, p.77)

Embodied tacit knowledge is knowledge of bodily or material form. It is both kinesthetic, related to movement of the body, and sensory, related to the human senses in which information enters the body (Bennet & Bennet 2008, p.78). The knowledge of riding a bike is a common example of Embodied knowledge. It is generally learning by mimicry and behavioral skill training, and while deliberate learning through study, dialogue and practice occurs at the conscious level, the knowledge often becomes tacit when significant or repeated over time. As individuals develop competence within a specific area, more of their knowledge becomes tacit, making it difficult to explain their knowledge explicitly. This understanding of embodied skill supports and complements Dreyfus' model, which we will return to in Chapter 4.3.2. The neuronal patterns representing the knowledge become embedded in long-term working memory where they become automatic when needed, but lost to consciousness (Bennet & Bennet 2008, p.78).

Intuitive tacit knowledge is the sense of knowledge *'coming from inside an individual that may influence decisions and actions'* without us being able to reason how or why the decision is right (Bennet & Bennet 2008, p.78). Our unconscious processing capability is many times greater than that on a conscious level, which is why we rely more and more on our intuitive tacit knowledge as the world grows more complex (Bennet & Bennet 2008, p.78). Intuitive tacit knowledge is a result of continuous experience with a phenomenon as long as immediate and accurate *feedback* is provided, and over time unconscious patterns are developed and the knowledge becomes a natural part of our lives. This is compatible with the *'Expert'* level in Dreyfus' model where an individual is so comfortable with the task that its execution is largely unconscious and automatic.

Acquiring tacit knowledge

The processes in which new tacit knowledge is gained can generally be categorized into a set of modes of learning all placed on a scale of intention. On one hand you have the now widely recognized phenomena of '*implicit learning'*, defined by Reber as *"…the process by which knowledge about the rule-governed complexities of the stimulus environment is acquired independently of the conscious attempts to do so"* (Reber 1989, p.219). In this mode, there is no intention for obtaining the often rich and complex knowledge, and the process happens independently of overt, conscious strategies for its acquisition (Reber 1989, p.221). On the other hand, '*deliberate learning'* is when time is set aside specifically for learning. Michael Eraut (2000) found it useful to introduce a third mode, called '*reactive learning'*, placed between the two, describing situations where the learning is explicit but takes place almost spontaneously in response to recent, current or imminent situations without specifically setting aside time for it.

Reber (1989) showed in his studies on tacit knowledge and implicit learning that participants were able to learn complex probability structures in a sequence of events in a relatively short time span. In fact, even when the participants were informed of the relative probabilities in advance, their performance was statistically indistinguishable from the control group without the instructions. It took real experience with the sequence to acquire a usable knowledge base, regardless of whether or not the participants were giving explicit instructions ahead of time. No structure could be derived from the events themselves, *"nevertheless, subjects reported achieving a sense of the nature of the event* *sequence from experience with events that they did not derive from the explicit instructions"* (Reber 1989, pp.222–223).

Several other studies found that informing participants would in fact decrease performance, showing that the explicit processing of complex information had a decided disadvantage compared to implicit processing (Reber 1989). The explicit instructions would seemingly cause an interference effect that would slow down the implicit learning process. The participants would search for rules they were unlikely to find, and worse, would make improper inductions that led them to hold incorrect rules about the stimuli. In short, they used all their time and energy trying to find patterns that were practically impossible to find, rather than letting the implicit learning process give them the pattern tacitly (Reber 1989, p.223).

4.3.2 Dreyfus Model of Skill Acquisition

Dreyfus 5-stage model *Novice-to-Expert* is used fairly widely to describe the different levels of expertise in the development of skills (Lester 2005). According to the model, which was first proposed in a paper in 1980 and later refined in 1986, people pass through 5 distinct stages before a skill is fully developed: novice, advanced beginner, competent, proficient, and expert (Dreyfus et al. 1987). The model is based on Merleau-Ponty’s work, and more specifically his notion of the ‘*intentional arc’*, the body’s capacity to act in order to change the presented situation (Merleau-Ponty 1962, p.136). Here it is useful to distinguish between three different understandings of embodiment (Dreyfus 1996):

1. *The anatomy* and innate structures of the human body, e.g. that it has hands, feet, a certain size and certain abilities.
2. *General skills* we refine as humans when coping with new situations, e.g. walking, jumping, reaching and grabbing.
3. *Cultural skills* we acquire through affordance with cultural objects or phenomenon, e.g. sitting on a chair.

With this view, each understanding of embodiment is dependent on the preceding level, so cultural skills require general skills, and general skills require innate human structures. To see how embodied skills are acquired through experiencing and responding to new situations, Dreyfus proposes his *Novice-to-Expert* model that more fully shows how our relation to the world is transformed through skill acquisition (Dreyfus 1996). Each stage in his model is briefly presented below, using a driver of a car as an example.

Novice

The novice skill level is assigned to someone who simply adheres to rigid rules or plans, with little contextual or situational perception. They also lack any discretionary judgment, and will perform actions solely based on the features according to the rules given.

The novice car driver recognizes interpretation-free features such as speed, and times gear shifts based on the current speed. This allows the novice to get started with learning the skill in question, but these actions break down under certain conditions.

Advanced Beginner

As the learner is experiencing real situations, examples of additional component of the situation emerge. After a sufficient number of examples, they become recognizable to the learner and instructional maxims can now refer to these new aspects. When reaching the advanced beginner stage, their knowledge is contextually related, but situational perception is still fairly limited. All aspects of work are treated separately and with equal importance.

The advanced beginner driver uses engine sounds and speed to guide him with the maxim of shifting up when the motor is racing and down when it’s straining. This requires examples of motor racing and straining sounds cannot be adequately explained using only words.

Competent

With increased experience, the amount of information from features and aspects to take into consideration becomes overwhelming. The performer adapts a hierarchical view of decision-making that organizes the situation and prioritizing certain actions becomes easier. In the competent stage, actions are now seen at least partially in terms of longer-term goals, and the learner is able to make conscious and deliberate planning and formulate routines.

A competent driver may decide he is going to fast when exiting the freeway on a curved off-ramp. He has to decide whether to let up the accelerator, remove his foot all together, or step on the brakes. He is relieved if he gets through the curve without any problems and shaken if he starts to skid.

Proficient

In this stage, the learner sees situations holistically rather than in terms of aspects, can prioritize what's the most important in any given situation and can spot deviations easily. Their decisions are now made with ease and they employ maxims for guidance, with meanings that adapt to the situation at hand.

Based on prior experience, a proficient driver on a rainy day going through a curve may, based on visibility, angle of road bank, road and tire conditions, criticalness of time, etc. sense he is going too fast. He will then decide whether to let of the accelerator, take his foot off the pedal, or step on the breaks.

Expert

An expert no longer relies on rules, guidelines or maxims, but instead has an intuitive grasp of situations based on deep a tacit understanding. They have a vision of what is possible and use analytic approaches only in new situations or when problems occur.

The expert driver knows by feel and familiarity when slowing down or shifting gear is required and does so with no awareness of his acts. He does not have to calculate or compare alternatives and simply does what he feels needs to be done in any given situation. He relies mostly on intuition rather than analysis and comparison of alternatives.

4.3.3 The Natural User Interface

The interaction between the user and system will be designed using the principles of a Natural User Interface (NUI). Simply put, a NUI enables us to interact with computers in the same ways we interact with the physical world, through using our voice, hands, and bodies (Preece et al. 2011, p.215). The NUI is considered the next generation of user interfaces (Blake 2010, p.2) following the Command Line Interface (CLI) from the 60s through 80s and the Graphical User Interface (GUI) (Liu 2010, p.203), which is still the dominant way we interact with computers today. The GUI was considered a computer revolution when it first appeared in the 80s together the introduction of the mouse. It was more capable, easier to learn and easier to use in everyday tasks compared to the CLI (Blake 2010, p.7) and as a result the entire industry had to adapt. Now, history is repeating itself with the introduction of the NUI, which is the more capable, easier to learn and easier to use technology compared to the GUI (Blake 2010, p.7). Like with the transition from CLI to GUI, the new will replace the old on general, everyday tasks, but not make GUI go away completely. CLI is still being used today for the specialized tasks it is best at, and this is also the case this time around. GUI’s will still be around, but the transition to NUI on everyday tasks is inevitable (Blake 2010, p.7).

While NUI is not a new concept, it is only in recent years that the term has entered the mainstream consensus (George & Blake 2010, p.2). As the technology has matured, and the need for better experiences on new form factors and screen sizes grew, more and more companies have developed mass-market products with NUI elements like the Apple iPhone, Nintendo Wii, Xbox Kinect, Leap motion and Oculus Rift that offer truly embodied experiences. This approach, drawing on the work of Merleau-Ponty and the lived body, is also increasingly common in NUI research (O‘Hara et al. 2013; Di Tore et al. 2013; Fortin & Hennessy 2015).

The characteristics of a NUI

We used Blake’s definition of NUI *“A natural user interface is a user interface designed to reuse existing skills for interacting appropriately with content”* (Blake 2010, p.4), However, to properly understand what a NUI is we will describe the unique characteristics of a NUI. These characteristics are natural, direct, intuitive, and invisible and will be explained in detail below.

Natural

The implication and meaning of the word *natural* in a NUI, is unfortunately also one of the biggest points of confusion about what a NUI really is (George & Blake 2010, p.2). The ambiguousness of the word allows for any designer to claim their work to be natural. Especially seeing as calling their work the opposite, un-natural, would certainly seems absurd. Most designers and developers in this field do not have extensive NUI research backgrounds and they often struggle with unclear ideas and mixed concepts. As a result, many NUI projects have significant usability issues (George & Blake 2010, p.2). An accurate constitution of the word in this context, was given by Bill Buxton (2010) who uttered *"[The NUI is] natural in the sense that it exploits skills that we have acquired through a lifetime of living in the world"*. He then elaborates and goes on to make the distinction between the truly natural, innate attributes like walking, eating, breathing and sleeping, and learned attributes, which are the skills we acquire during our lifetime as humans, like riding a bike or tying our shoelaces. What sets NUI apart from traditional user interfaces is that it recognizes that skills are expensive to acquire, so rather than forcing the user to learn a new skill, like navigating a GUI or operating a control panel, we utilize the tacit knowledge and skills the user has already learned about the world. This could very well be a complex skill requiring years of practice, such as playing an instrument, as long as leveraging the target group to users with this particular skill is desirable.

Direct

With the emergence of the GUI, one of the things that made it much easier to learn and use for most tasks was how manipulations could be done directly, in a similar way to how we interact with objects in the real world. Moving a file such as a document to a folder, could be done more directly than before by dragging the documents icon on top of the folder icon. In this case, the icons are metaphors for the physical representation of the document and folder, and the dragging action of the document to the folder is a metaphor for filing the document inside the folder. This, and other related actions from introduction of the GUI, was at the time deemed "direct manipulation" by Ben Shneiderman (1993). Today, while these actions are certainly more direct than by typing a command in a CLI, it is not considered very direct (Blake 2010, pp.7 – 8). That is probably because NUI interaction patterns have now been introduced to us and shown us much more direct style of interaction. Such as swiping the finger to the left to turn to the next page in a book or the next picture in a picture gallery, pinching your fingers closer or further from each other to zoom in or out, or swinging a Wii-remote to swing the characters tennis-racket on the screen. These interactions are more direct in the sense that they are closer to the interactions we would have with a physical book, a stack of photographs, or a real tennis-racket.

Intuitive

NUI is to a large extent the exclusion of metaphors to be more direct, and the utilization of existing skills to be more natural, which should ideally result in a more ‘intuitive’ user experience. However, the concept of intuition in a HCI context is problematic because it lacks a sufficient level of precision and means different things to different people. Bakke (2014) present the term ‘immediacy’ as a more precise term describing an *‘immediately understandable UI’* to users within a specific context. It relies on the users’ experience-based intuitive approach to the task, combined with the mediated affordances present in the UI. This understanding, combining contextually relevant skills and affordances, can give us a more precise meaning of intuition in an interface. Further, we can employ a tacit understanding of the term, describing knowledge coming from within that guides decisions or actions where an individual is unable to reason for how or why the decision is right. By using this combined understanding, intuition can be facilitated by allowing the users’ already acquired skills to be triggered with the affordances of the UI in a way that makes the interaction feel as real as the context it represents, creating instant familiarity with the task and allowing the user to tap into their unconscious, intuitive tacit knowledge. It should be emphasized that this does not necessarily mean that the interface should be an imitation of the real world. It should simply reuse existing and appropriate skills in the interaction, making both expert and novice users alike feel right at home.

Invisible

We typically don’t think of what allows us to understand verbal information spoken to us by another human as an independent ‘layer’ or ‘interface’ that is processing the information. Similarly, a NUI interface should be effectively invisible in the sense that it allows input from the user to presumably directly affect the artifact, creating the illusion that no technology-layer is present. A concrete example would be the difference to zooming in or out on a map in GUI vs NUI context. With a traditional GUI, you would expect to find buttons for zooming on and out, or perhaps a sliding bar that can be dragged with the mouse, while the NUI could allow zooming to be done by pinching of the fingers. This eliminates the need for graphical elements, causing the interface to seemingly disappear from the screen. Cues (visual or other) are obviously still allowed and even necessary in many situations, but ultimately the design and required skill together should afford appropriate actions. This is similar to ubiquitous computing, where the system is so imbedded, fitting and natural, that we use it without even thinking about it (Weiser 1994). The computer is shifted to the background, only visible through the services they provide (El-Khatib et al. 2003).

4.4 Framework: Application of Theory

As mentioned in the introduction, the theoretical framework is based around the six aspects that we consider relevant to balance as input. These are:

1. Intuition
2. Learnability
3. Feedback
4. Reusability
5. Affordance
6. User Experience

Based on the three theories, tacit knowledge, Dreyfus model of skill acquisition and NUI, these six aspects are presented below in light of the three theories.

4.4.1 Intuition

The intuitiveness of balance is arguably the most important to evaluate, and this is why it is also part of the research question. This is because the main argument for utilizing postural control in this setting is its potential for being intuitive because of humans’ natural use of reactive postural control to counteract any threats to our balance anyway. According to the framework, intuition is understood as an unconscious processing of a task that takes advantage of already acquired skills to facilitate an immediate understanding of how something works within a specific context. The intuition of the balance interface should thus reuse the users’ own sense of balance to enable the humans to understand how the UI works almost immediately. This stems from a combined understanding based on all three theories: Tacit knowledge (primarily the aspect of intuitive knowledge as described on p.27), Dreyfus model (expert level, p.30) and NUI (intuitive interfaces, p.32). As an interpretive research approach has been applied, intuition should not be measured in an objectivist manner, i.e. through careful and precise measurements, but instead in terms of how intuitive the use of bodily balance is *perceived* as an input modality to users. Consequently, the criteria for evaluating the intuitiveness of balance is the users’ own experienced intuition with the interface.

4.4.2 Learnability

Learning is understood through multiple theoretical perspectives. With the concept of implicit learning, we understand a type of learning where the knowledge is too complex to be explicitly taught and that can only be acquired through experience. Specifically, the knowledge we are referring to is embodied knowledge of the kinesthetic sense and posture control. Further, we used Dreyfus’ model as a frame of reference when it comes to the different skill levels. This allows us to evaluate both the ease of use and learnability of the interface by examining the improvement in skill over time. Thus, learning is evaluated based on improvement in skill during testing, not through simply following instructions, but through the process of implicit learning as users are interacting with the interface and are increasing their embodied understanding of how movement results a response.

4.4.3 Feedback

Feedback is primarily understood through the tacit knowledge concept of intuitive knowledge and Dreyfus' model, where we consider balance as a skill that the user has already acquired, locatable within his 'novice-to-expert' model. Feedback refers to the system response that lets the user know input has been received. Feedback is an important aspect in the framework because appropriate and immediate feedback is a crucial prerequisite to the development of tacit intuition (as outlined on p.27). Furthermore, with the human balance system providing feedback to any postural changes instinctively and tacitly, it highlights the importance of reflecting this with equally accurate feedback from the system that is in-line with the users' expectations. The question is therefore not simply if feedback is provided or not, but *how* and *when* it is provided. As a result, feedback is also concerned with the related terms responsiveness (how fast is feedback provided?), accuracy (is the level of feedback as expected based on the input?), and precision (is the resolution of the provided feedback adequate?). Because of the mobility context, the primary mode of feedback is movement, but visual or audio feedback may also be used as supplements.

4.4.4 Reusability

Reusability of skill is one of the central concepts of a NUI, and refers to taking advantage of existing human skills the user already has and reuses them in the interaction. Thus, the ability for the skill to transfer over to a new context is crucial for its success, and this relies on skill afforded actions being appropriately mapped to functions in the interface. Reusability is therefore evaluated through the balance skills' ability to *transfer* to the new context with as little need for relearning the core actions as possible. The learning process should consist mostly of the user familiarizing themselves to the new situation, instead of having to learn how to perform the appropriate actions.

Reusability should not be confused with the related term *'memorability'* because reusability of skill describes a situation where the new task is different from the old task. As such, it is not something that can be memorized, but instead a core skill that is *reused* in a different context. With reusability, the user does not have to learn a new skill from the beginning, but merely use the same skill when performing a new task. According to Dreyfus' model, this requires that the two skills are closely related, i.e. that they include a similar set of actions. The closer they are related, the better they are able to transfer over to the new task. A distinction between tacit skills should also be made, because reusability is in fact more than tacit skills. Specifically, it is the reuse of tacit skill in a new and unfamiliar context.

4.4.5 Affordance

We consider affordance especially relevant in NUIs and thus, the term is understood primarily through the concepts of invisible and natural. At first glance, one might consider invisible to be a contradiction to affordance, because how would one know how to use something that cannot be seen? However, as outlined on p.32, invisibility refers to the technology and not the artifact and thus, providing proper affordance to give a clue about how to interact becomes even more important. One such approach is to rely on the affordances of similar non-technological artifacts and extend or build on their already established usage-patterns. Similarly, the term natural, can shed light on the affordance issue because objects that lack any attributes hinting towards their use will likely require explicit instructions or trial and error, thus the interaction is not natural and affordance is needed. We see affordance as a particularly important aspect in relation to balance because unlike most other forms of user input, postural changes do not need any visually manipulable elements.

4.4.6 User Experience

User Experience (UX) is a common benchmark of success in computer systems (Preece et al. 2011), but it is perhaps even more common in NUI based systems. The term *natural* in many ways implies a certain level of user experience, because it requires that the interaction comes naturally, just as it does in the physical world. We also consider the term *direct* to enable increased user experience, because a more direct interface limits the abstraction and in turn narrows the gap between action and intent. We limit ourselves to the following UX goals: fun, enjoyable and satisfaction (Preece et al. 2011, p.26).

4.4.7 Theoretical framework overview

An overview of our theoretical framework is presented below. It is constituted by the six aspects described above and lists the corresponding relevant theoretical concepts described earlier in this chapter. It also shows the criteria of which the aspects will be evaluated against and the related work that use these aspects on some level (see Figure 3.1 for reference list).

Table 4.1 Our theoretical framework

#	Aspects	Theoretical concepts	Criteria for evaluation	Related work
1	Intuition	Intuitive knowledge, Novice-to-expert, Intuitive (NUI)	Experienced intuition	[1, 2, 3, 4, 5, 6, 7, 8]
2	Learnability	Implicit learning, Embodied knowledge, Novice-to-Expert	Skill improvement during test	[1, 2, 4, 5, 6, 7, 8]
3	Feedback	Intuitive knowledge, Balance as a skill	Tilt preference, motion feedback, visual feedback	[1, 2, 3, 7]
4	Reusability	Natural, Balance as skill, Embodied knowledge	Transferability	[1, 3]
5	Affordance	Invisible, Natural	Visibility of prototype UI elements	[8]
6	UX	Natural, Direct	Fun, enjoyable, satisfaction	[7, 8]

5 Method

5.1 Research Methodology

With the theoretical framework in place, we will present the methodological approach for answering the research question: *"Can balance alone be used to control a personal mobility device in an intuitive way?"* One of the core activities in HCI is to conceive, propose, design and implement new technologies through the creation of prototypes which in some way test new interaction patterns or interface solutions (Fallman 2007). However, while applied researchers, consultants and designers from industry typically apply a research-orientation to their design ideas, we subscribe to a different approach in this thesis. Instead of trying to *solve* a problem using a research-orientation to propel our design, and where the production of a new artifact is the main contribution, we instead want to *answer* a problem by relying on a *design-orientation* to our *research*. In design-oriented research knowledge is the main contribution, and specifically such knowledge that would not be attainable if design was not a vital part of the research process (Fallman 2003). The resulting design is used as a means for conducting research and gaining new knowledge, similar to how a natural scientist must first create the tools of which to study the proposed phenomena before testing the theory (Fallman 2007). We emphasize that this is not to say that practitioners of research-orientated design never produce new knowledge from their design process, and the design derived from design-oriented research is without value. The difference lies in what is considered the main 'result', and the number one motivator of the study.

> *"In design-oriented research, the knowledge that comes from studying the designed artifact in use or from the process of bringing the product into being is the contribution, while the resulting artifact is considered more a means than an end. […] In contrast, research-oriented design is a term we believe better illustrates the relationship between consultants, applied researchers, designers from industry, and HCI design" (Fallman 2003, p.231).*

To answer our research question, one would ideally evaluate a working device such as a PMD prototype with a balance controlled user interface, and this approach has been chosen for this study. Specifically, design will be used to demonstrate a research contribution through user testing of a prototype. The goal is to determine the perceived intuitiveness of the prototype interface while the designed artifact itself is of secondary importance, hence the design-oriented research methodology. However, while design-oriented research determines how new knowledge will be gained, a strategy for completing the actual design process is outside its scope, and here we will turn to User-Centered Design (UCD).

5.2 User-Centered Design

User-Centered Design (UCD) is an iterative design process with an early and continual focus on users and their tasks, usually through the active involvement of users throughout the design process (Karat 1997; Wilson et al. 1997; Bekker & Long 2000; Mao et al. 2005). UCD was first coined in Norman & Draper's seminal book 'User-Centered System Design: New Perspectives on Human-Computer Interaction' (1986), where UCD is described in the following way:

> *"[…] user-centered design emphasizes that the purpose of the system is to serve the user, not to use a specific technology, not to be an elegant piece of programming. The needs of the users should dominate the design of the interface, and the needs of the interface should dominate the design of the rest of the system." (Norman & Draper 1986, p.61)*

With this definition, actual user involvement is not required by necessity, however it is generally agreed upon that active user involvement is the best way of ensuring that the requirements of the users are met (Bekker & Long 2000; Dwivedi et al. 2012). Since its introduction, many definitions of UCD have been proposed, but no single agreed upon definition of UCD exist (Karat 1996; Gulliksen et al. 2003). Some see the lack of a shared understanding of UCD as a strength in its own right, where the openness and flexibility of the methodology allows it to adapt to virtually any design project (Karat 1996). Others consider this ambiguity a weakness diminishing its relevance (Gulliksen et al. 2003). We see the flexibility of UCD as an advantage that allows our interpretive, mixed method approach to be fully compatible. Today, UCD has become the dominant design methodology in the industry to such a degree that it is accepted and practiced by designers automatically and uncritically (Norman 2005; Bowles 2013).

5.2.1 The UCD process model

Usually, the UCD process consists of a similar set of stages or activities as the stages of Interaction Design, described by Preece et al. (2011, p.15) as:

1. Establishing requirements
2. Designing alternatives
3. Prototyping
4. Evaluating

In the UCD process model, the steps are first carried out in sequence. After the evaluation, the process continues with the appropriate stage to improve the solution based on the feedback from the evaluation. This iterative process allows new and changing requirements to be included with relative ease, and the process continues until the designed solution meets all user requirements. The individual steps themselves can vary slightly from project to project. For example, by separating the requirement specification from the contextual inquiry to create a 5-stage model or grouping together the prototyping and designing into a single stage. In this thesis, a 4-stage model similar to the Interaction Design model was considered to be the best fit, but the background chapter can be seen as a stage of its own and is thus included as “Stage 0”. Table 5.1 presents the methods for each stage, as well as input and output for each method. The final model used can be seen in Figure 5.1.

Table 5.1 Method overview of the design life cycle

Stage	Input	Method / Task	Output
Stage 0: Background		Analysis of current PMD categories	PMD analysis
		Review the literature on related research areas	Literature review
Stage 1: Needs analysis	PMD analysis Literature Review	Online Survey	Requirement specification
		Review of related transportation research	
Stage 2: Design	Requirement specification	Focus group with brainstorming	Initial design concept & paper sketches
		Design workshop	
	Design concepts	Review of related products	Paper prototype implications
	Design concepts	Low fidelity prototyping	Paper prototype

Stage	Input	Method / Task	Output
	Paper sketches		
	Paper prototype implications		
Stage 3: Implement	Paper prototype	High fidelity Prototyping	Functional prototype
	Requirement specification		
Stage 4: Evaluate	Functional prototype	Usability testing	Test results
		Qualitative observations	
		Informal discussions	
		Paper survey	
	Test results	Analysis	Conclusion

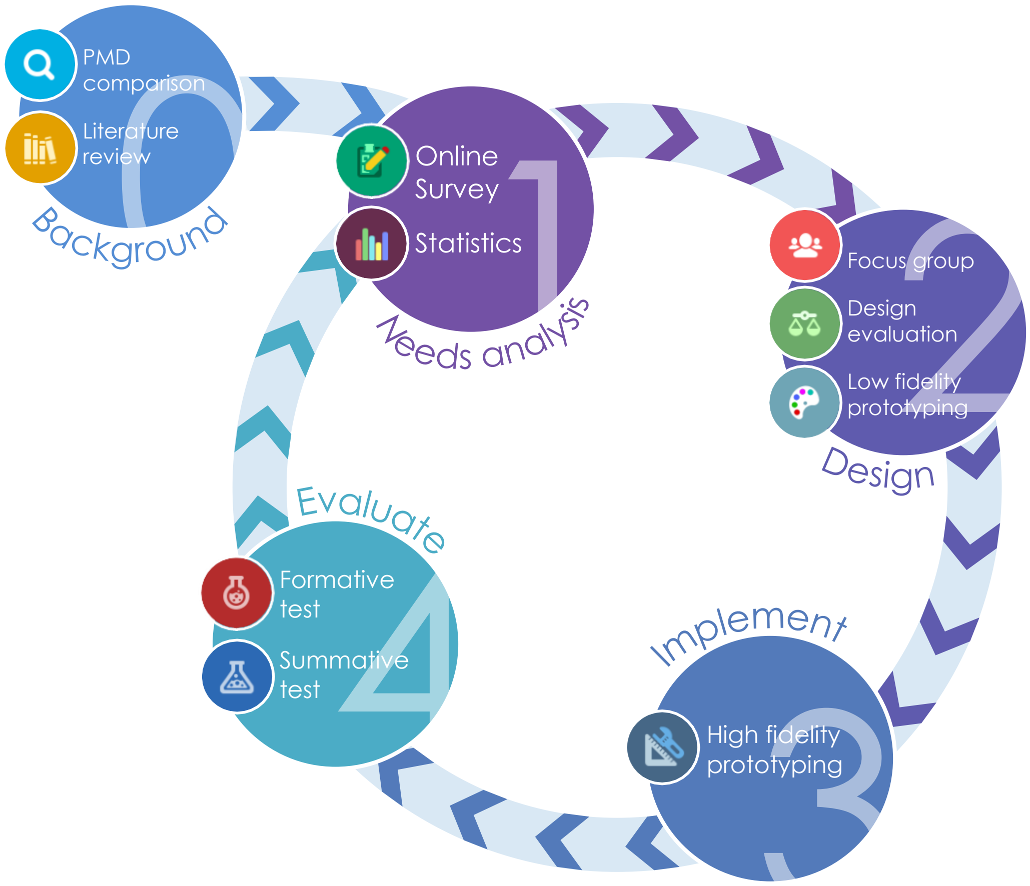


Figure 5.1 The UCD life-cycle model used in this thesis

5.3 Stage 1: Needs analysis

The first step in the UCD process is to define who the users are, their tasks and goals, their experience levels and what they want and need from the system (Katz-Haas 1998). This is important to ensure informed decisions in the later stages of the design life cycle. For this purpose we have chosen a needs analysis which is defined as the process of identifying and evaluating needs in a community or other defined population of people (Titcomb 2000). The needs analysis will mainly consist of an online survey to identify preferences, habits and experiences related to PMDs and short distance transportation. This data will be triangulated with an evaluation of already published research on PMDs to verify and extend the results of the survey. Drawing on the background chapter and literature review, the overview of the first stage is presented in Figure 5.2.

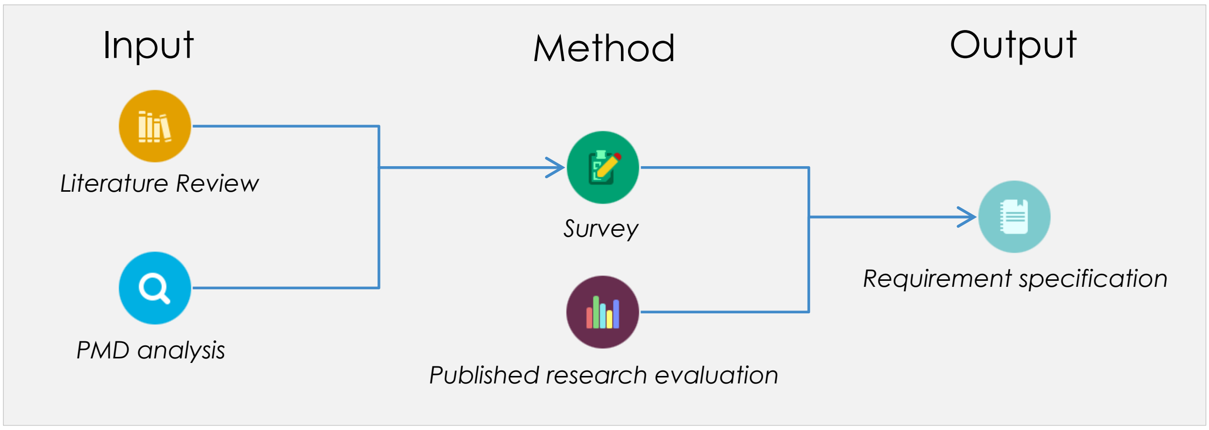


Figure 5.2. Overview of methods used in stage 1 of the design life-cycle

In the research stage, the goal is to get an insight into people’s perception towards PMDs and identify the important attributes of the prototype in order to inform the design according to user needs. The focus in this stage is on the artifact attributes rather than the interface itself. This is because the research question is about the perceived intuitiveness of using balance as input, and we would argue that for this to be sufficiently answered users must be able to experience a working interface on a working device in realistic and contextually accurate environment. Thus, the evaluation of the interface will be subject to inquiry only once a working prototype has been constructed.

One might expect a more qualitative study with our interpretive research approach. However, it should be emphasized that the goal of stage 1 was to specify a target group and identify a set of needs, and these needs are not related to factors of balance, but to the more tangible needs of the artifact itself. Subsequent stages following the needs analysis will have a much bigger focus on qualitative methods, but for this stage gathering data from a diverse group of people to gain a broader view of PMD needs was the priority. Thus, two primarily quantitative methods were chosen, but the quantitative data was qualitatively validated through online discussion forums as well as the methods in stage 2.

5.3.1 Online survey

A survey is an excellent way of getting a large number of responses quickly from a large and geographically scattered sample in a population (Lazar et al. 2010, p.100). While the collected data is not as in-depth as other research methods, it is effective at capturing the big picture relatively quickly. We have chosen to use a survey to identify user needs and requirements in the prototype, and to get an insight into people’s perception towards PMDs. Using a survey to gather needs raises some interesting issues related to the degree of which users are able to predict or articulate what they will want in a product in advance. Users are known to be bad at predicting future actions, and will often unwillingly lie in surveys. Consequently, by asking participants directly for their requirements in an imaginary product, we risk getting requirements similar to that of existing products, limiting the room for innovation. Instead a different approach was used where the participants were asked for requirements *indirectly* by asking them to assess various attributes like the size, weight, safety and speed of a set of existing designs that they are already familiar with. This resulted in a list of good and bad attributes for various PMD product categories and this would lay the foundation and act as a starting point in the upcoming design stage.

In addition to needs and wants, the survey would also be used to gain a better understanding of the user and their context by estimating the current PMD install base in Norway and to find out approximately how common previous PMD experience currently is. Additionally, the survey was used to identify which transportation options people use instead of PMDs to indicate what these devices, if successful, could be replacing in the future.

The target group was Norwegians with transportation needs aged 16 and up, and particularly people living in urban areas. The timeframe was set to approximately 2 months. Lottery incentives for participation was considered, but was ultimately dropped. This was both because of possible bias, but also because research shows the effectiveness of incentives to increase response rate is very limited. In a meta-study of 68 internet-based surveys, Cook et al. found that incentives actually decreased the overall response rates (2000). The authors postulate that this may be because many associate surveys with incentives to be longer and more tedious to complete. Other studies have investigated the effect of postpaid incentives, where the general findings are no statistically significant impact on response rates for payments of $5-$20 (Berk et al. 1987), as well as non-monetary incentives.

Designing the survey

The survey was designed as an online survey and participation would be anonymous to simplify legal issues related to the storage of respondent data. Questions about age and sex were included, but the survey did not ask for, nor linked answers to, any personal data including e-mails or IP addresses, thus the survey was not subject to notification to the Data Protection Official for research under the Personal Data Act (NSD 2012).

The questions consisted of mostly multiple-choice answers with checkboxes or radio buttons. Qualitative questions in free text form (such as "Other" in multiple choice questions), was included where necessary to give the participants an opportunity to elaborate and give open-ended answers using their own words. To guide the survey design we used a guide for designing effective online surveys compiled by Survey Monkey based on various research (2008), with a focus on the following points: brevity, survey length, using the participants' language, objectivity, avoiding assumptions and survey layout.

Pilot

Following the survey design, a 1-week pilot period was conducted to properly test the survey. In the pilot, a few fellow students were asked to test the survey. Larossi (2006, p.89) lists three goals of the pilot test. First, evaluating the adequacy of the survey, i.e. ensuring that the questions, as they are worded, will accurately answer what is intended, such as ensuring that the participants understand what the survey is about and that the wording and themes discussed are clear. Second, establishing the time needed to complete the survey. This was accomplished by measuring the time participants used to complete the survey with a simple stop-watch. The mean time of 3 minutes was displayed as the estimated time required for completion on the front page. Finally, to ensure a high quality of questions and answer options. This included identifying biased or unclear questions, looking for missing or abundant questions, or technical issues, such as verifying that the right questions would be visible in the right cases. The survey design was adjusted accordingly as feedback from the testers was received.

Conducting the survey

Recruitment of survey participants happened in various online and offline settings. First, the survey was posted on Norway's two largest general-purpose forums[2]. On each forum a thread was posted asking for participation in the survey, while at the same time starting a discussion about small electric vehicles in the thread itself. This discussion not only added to the popularity of the thread, repeatedly bumping it the top of the list while increasing the chance of more people participating, but also added deeper, qualitative data that would enrich the data collected from the survey. The discussion was meanwhile facilitated by the original poster, asking questions about new topics within the field of PMDs and ensuring a continuous discussion.

Recruitment continued at my workplace where I sent out emails asking for participation, as well as asking students and friends on Facebook.

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[2] The two forums were VG debatt (vgd.no) and Diskusjon.no.

5.3.2 Review of related transport research

In order to gain a more complete picture of the user and get a sense of the context of use, a review of already publicly available statistics was conducted to extend and verify the knowledge of the user and use context. Three reports were chosen and evaluated for this task; two from The Norwegian Institute of Transport Economics (Transportøkonomisk institutt, TØI) and one from Urbanet Analyse (UA):

1. Report on Norwegians attitude towards e-bikes (Fyhri & Sundfør 2014)
2. Market research on bikes in four Norwegian cities (Loftsgarden et al. 2015)
3. Norwegian national travel survey 2013/14 (Hjorthol et al. 2014)

The first report is about the effects of, and attitude towards, e-bikes in Oslo and Akershus and thus relevant to the project in understanding who PMD users are and the impact PMDs will have on society. The second includes the results from a survey on bikes in four Norwegian cities as part of a bigger project to inform targeted measures to increase bike use in these cities, which will be used both to gain a contextual understanding of PMDs and to understand why people chose or don't chose a bike as transportation. The final report is Norway's largest travel study on travel habits in Norway which was used to understand the current transport situation in Norway.

With this evaluation, our goal is to gain contextual understanding of PMDs in Norway and how these devices fit in the current transportation landscape. Additionally we want to increase our understanding of the potential users and their needs for the requirement specification.

5.4 Stage 2 Design

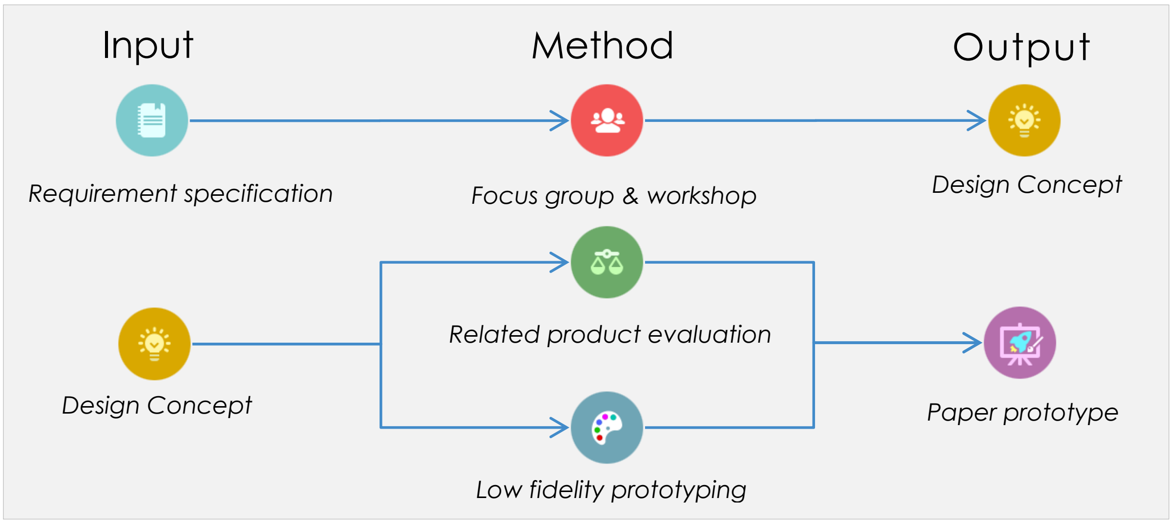

Figure 5.3 Overview of methods used in stage 2 of the design life-cycle

In stage 1 we focused on gathering requirements and understanding the context of use, and in this stage we will use these results to create a design concept and paper prototype that will take advantage of the users' balance skill in its interface.

5.4.1 Focus group and design workshop

The process from requirements to design was initiated using a focus group. A focus group allows for collecting information from multiple perspectives in a group in a systematic and structured format, and was selected because of the easy access to students with previous design experience studying at the department. Focus groups are also common methods to use in combination with surveys, the primary method of the research stage, and the pairing of these two methods is one of the leading ways of combining qualitative and quantitative methods (Morgan 1996, p.134). By using design students, information from a group of people who are not only in the target group (and are end-users in relation to PMDs), but also have extensive design experience, could be gathered fairly quickly. Because of this, the focus group was coupled with a design workshop, allowing the participants to create simple paper prototypes following the focus group discussion. The aim of this method was to add a qualitative layer to the survey findings through discussions of the results, and to go from the requirement specification from the research stage, to an initial set of design concepts. In particular, the participants would help identify opportunities and challenges related to UX, affordance, feedback and learnability of the interface in the concepts.

The focus group and design workshop was conducted over 2 hours and included seven participants. All participants were master students associated with the Department of Informatics and five of them were studying on the Design, Use, Interaction program. Thus, they were familiar with concepts such as UCD, UX, prototyping and the phenomena outlined in our theoretical framework. The format of the session was as follows:

- A brief introduction of the project
- Presentation of the survey results in the previous stage
- Brainstorming design concepts that match the presented requirements
- Discussion of generated ideas in relation to survey results and the balance interface
- Paper prototyping of two of the design concepts in groups
- Each group presents their concept to the others

The focus group did not have a structured set of questions and instead used the results from the previous stage to fuel the discussion around PMDs in general and if and why the participants agreed or disagreed with the survey results. During the brainstorming, the participants were asked to think of existing man-powered means of transport as inspiration, and envision motorized vehicle concepts based on these. The concepts were discussed in relation to the survey results, the opinions of the participants and the balance interface, and two of the concepts were selected for the paper prototyping stage. The participants teamed up in groups of two or three and created one simple paper prototype for each concept, using post-it notes of different colors to represent the location of the motor, battery and electronics. Finally, each group presented their design to the rest of the group as well as their thoughts on how the balance interface would work.

5.4.2 Investigation of similar solutions

In any design process it is useful to be aware of similar designs that already exist, and this project is no exception. There exists a wide array of electric skateboards already, and by studying their designs, we get a good idea of what works, and perhaps what doesn’t, without having to reinvent the wheel. A design concept, a set of sketches from the design workshop, and a first iteration paper prototype, and we can study other electric boards to identify opportunities and challenges for the next prototype iteration. This investigation did not contribute to improving the balance interface of the prototype in any meaningful way, and as such did not directly contribute to answering the research question. However, it did help with informing and accelerating the design process of the prototype overall, especially related to mechanical engineering issues such as mounting the motor and connecting the motor to the wheels. These issues, while not directly relevant to the research question, are still important to solve in order to construct a fully functional prototype, and as such this investigation was still a valuable step in the design process and provides an insight into some of the design decisions made.

5.4.3 Low fidelity prototyping: Paper prototype

Prototyping is recognized by designers from many disciplines as an important aspect for examining problems and solutions of design, and the prototyping process is useful in itself as it encourages reflection in design (Preece et al. 2011). A low fidelity paper prototype was created with the goal of converging the various design concepts that were created during the workshop into a single unified design. This was accomplished by combining the ideas from the workshop with what we learned by studying similar products into a paper prototype. As low fidelity prototypes are quick and easy to make, they also encourage modification and exploration and thus are ideal for the early stages of development around the same time as the conceptual design is established (Preece et al. 2011).

This process was carried out in parallel with the design evaluation described above. Multiple drawings were made in two iterations. First, a simple prototype following the conceptual design from the workshop that was later revisited after the design evaluation had been completed. Appropriate changes were made in the second iteration prototype according to the design evaluation results.

According to Houde and Hill (1997), the complexity of interactive systems requires the specific focus of a prototype to be made explicit. They propose a model for describing what a prototype is meant to prototype by placing it onto a three dimensional space, which is shown in Figure 5.4. The three dimensions show to which degree the prototype answers a specific question:

- What *role* will the artifact play in the users' life?
- What is the *look and feel* of the artifact?
- How should the artifact be *implemented*?

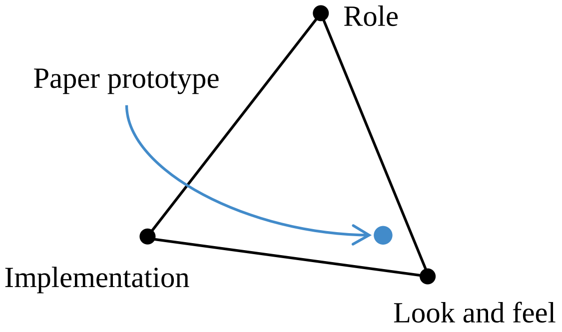

Figure 5.4. The paper prototype located within Houde and Hill's prototyping model (1997)

The paper prototype design is meant as a guidance tool for the construction of the functional prototype. Consequently, the prototype is mostly prototyping the look and feel of the artifact. However, the role of the prototype is also of some interest. For example, the artifacts role includes that it must work well in an urban environment and this will have implications on the design, such as wheel sizes and ground clearance. Furthermore, other design choices will have implications on the implementation such as the placement of technical components. Therefore, the paper prototype is prototyping parts of the role and implementation, but mostly the look and feel.

One thing worth pointing out is that the low fidelity prototype was not tested or evaluated by potential users after the fact, as is often the case in other UCD projects. The reason for this stems from the design-oriented research approach that has been applied in this study. Since the goal with the prototype was to answer questions related to its interface, look and feel related issues were not critical to evaluate and since the low fidelity prototype is mainly an increase in fidelity from the user-created sketches, retesting the low fidelity prototype was not prioritized. Its primary function was to guide the upcoming implementation stage and unify the sketches made by the participants in the workshop and to this end, doing multiple low-fidelity prototype iterations was not a priority.

5.5 Stage 3: Implementation

In the prototype stage we set out to build a functional prototype based on our design specification from the previous stage and the requirement specification from the first stage. Our goal with this stage was to get a prototype that was sufficiently functional to be evaluated by potential users, which entails a prototype with a working balance interface that controls the drive train. Figure 5.5 shows the overview of the stage 3.

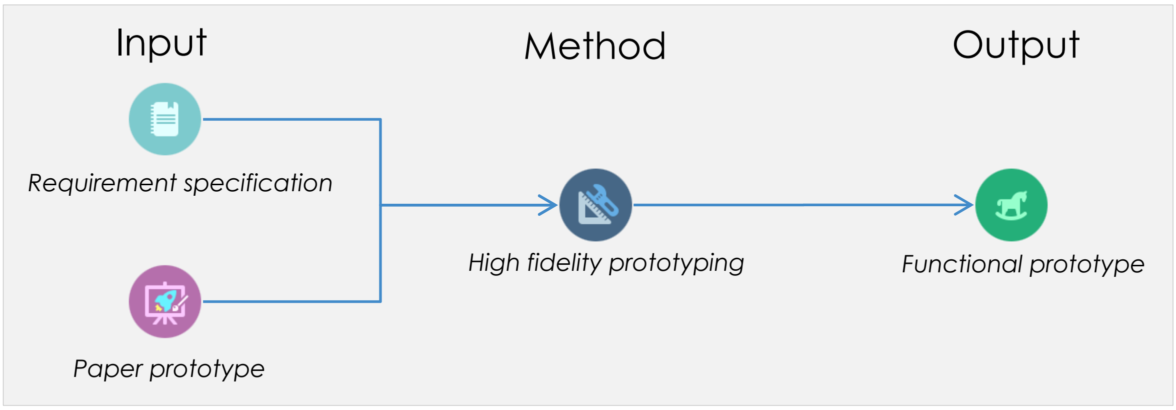

Figure 5.5. Overview of methods used in stage 3 of the design life-cycle

The prototype starting point was a standard longboard which was modified by adding load cells to measure the riders' weight distribution for the balance interface and a motor and transmission to drive the wheel. The entire prototyping process is documented in Chapter 8 (page 81). Aspects of the design that were not directly related to user needs, such as strictly technological choices (battery, motor, electronics etc.), were mostly informed through the design evaluation of similar products, where the technology was not conflicting with user requirements. The prototype went through two main iterations, and the initial testing in stage 4 provided valuable feedback for improving the prototype in the second iteration, both in terms of the interface from a users' point of view as well as the technical implementation.

The prototype, while functional in terms of mobility, was not fully featured as a holistic mobility device, and was designed specifically with the balance interface and theoretical framework in mind. It can therefore be classified as a vertical prototype that is a striped down version of the artifact. At the same time, some features outside the core focus of inquiry, such as headlights, taillights, Bluetooth and mobile app support, have been developed and implemented. This was primarily done to simplify troubleshooting and add additional means of feedback as well as the ability to override the balance interface before it was working reliably.

Figure 5.6 shows the high fidelity prototype placed within Houde and Hill's prototyping model (1997). While the paper prototype from stage 2 was for the most part prototyping the look and feel, the high fidelity prototype is an integrated prototype that prototypes all three aspects, thus placed within the inner triangle. The high fidelity prototype is however more focused on prototyping *implementation* in terms of including a fully functional interface and *role* in terms of providing participants with urban transportation. It is also prototyping the *look and feel*, in terms of being designed to look very close to a normal longboard, but this aspect of the prototype is of less importance at the current stage.

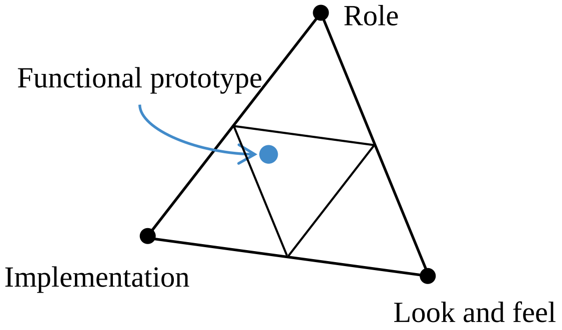

Figure 5.6. The functional prototype located within Houde and Hill's prototyping model (1997)

5.6 Stage 4: Evaluation

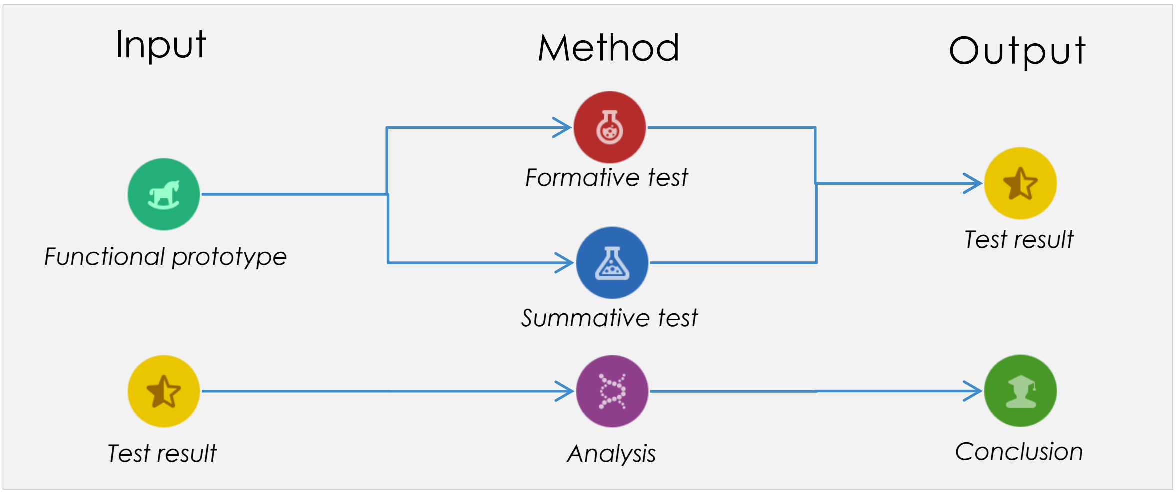

Figure 5.7 Overview of methods used in stage 4 of the design life-cycle

5.6.1 Formative usability test with balance simulation

The initial testing of the design was conducted before the balance interface was fully implemented, with the goal of getting feedback on the design as a whole as well as how the balance interface should function. In the test, the balance interface was simulated using a balance slider on an app and mobile phone. The phone was connected to the board via Bluetooth and controlled the power of the motor.

The usability test (N=14) was conducted indoors in a long hallway at the Department of Informatics over the course of three days. Participants were recruited from the students that were studying in close proximity from the hallway. The prototype spawned much attention from bystanders, but many were too afraid to try it themselves and only wanted to watch. The participants were observed while executing a set of basic tasks such as acceleration, maintaining a constant speed, turning and breaking. After the test, they completed a short, one-page form about their thoughts on the design and balance interface. Each test took only about a minute to complete, but many participants wanted to try it for a longer period. All participants were students at the department (both bachelor and master students), aged between 20 and 31. The simulation of balance was carried out by asking participants to lean forwards to put weight on the front of the board to accelerate. The participant could then increase the throttle using the mobile app.

5.6.2 Summative usability test with the final prototype

Final testing (N=17) of the completed prototype with a working balance controlled interface was conducted towards the end of the study once the implemented functionality was sufficient for user testing. This test followed a similar setup as the previous one in a controlled environment, but it was conducted outdoors using both prototype 1 and prototype 2 so that each participant could get more time to test and get a better sense of how the device controlled and felt in use. The participants filled out a 2-page paper survey following the test answering questions about the interface and prototypes overall. These questions were carefully chosen based on the different aspects of the theoretical framework, and included questions about experienced intuition, learning, UX and more. It consisted of a mix of Likert scale question such as *“Riding using balance became easier during the course of the test”* or *“My balance movements were registered as I expected”*, and open ended questions such as *“What should have been different? Were certain actions more difficult to perform than other actions?”*

Motivated by our phenomenological approach, we chose to observe the participants and to have informal discussions with them about their experiences while taking notes. Observation was chosen because it allows us to answer question that are hard to express with words, and this is a recurring method in phenomenologically grounded research (such as Larssen et al. 2004; Moen 2005; Loke et al. 2006). In our case, it was especially useful to determine the participants’ skill and stability on the board, as well as their learnability, i.e. how successful the interaction is over time. However, since the inquiry was focused around the participants’ personal experience, we cannot rely on observations alone. Thus, an extra emphasis was put on what they expressed about their experiences, rather than our assumptions based on what we observed alone. We also did not record errors or time spent, and refrained from providing the participants with a specific set of tasks to complete. Instead, our observations were focused around whether they interacted successfully, and *how* they interacted with it. As mentioned, we were not particularly interested in measuring performance, but instead wanted to understand balance as an input mechanism and to what degree using balance felt natural and intuitive to use in the interaction, and observations alone are not sufficient to answer this question.

Most of the participants were students and were recruited for participation on the spot, except for a few participants who knew about the test in advance. Several people walking by got interested and wanted to try on their own initiative when they saw it in use by other participants. Each participant could try for as long as he/she wanted, as long as the queue of waiting participants did not grow too large, and many of the participants got a chance to test both prototypes. To optimally facilitate the implicit learning process of embodied knowledge, only the most basic instructions about how to get on, turn, accelerate, break, and get off were provided, and during testing the participants were largely left to learn how to control the prototype through their interactions with it, and through the prototypes' response to their movements.

6 Stage 1: Needs analysis

The following chapter presents the results and analysis in Stage 1. The results from the online survey and evaluation of published transport research are presented separately in Chapter 6.1 and Chapter 6.2. Finally, we analyze the results of the entire stage and present our requirement specification in Chapter 6.3.

6.1 Survey Results

In the end, the survey was completed by 248 participants. The participant's gender distribution was 19,0% female to 81,0% male, and the age distribution mean was 37,83 years old with a SD of 3,19 years (see Figure 6.1).

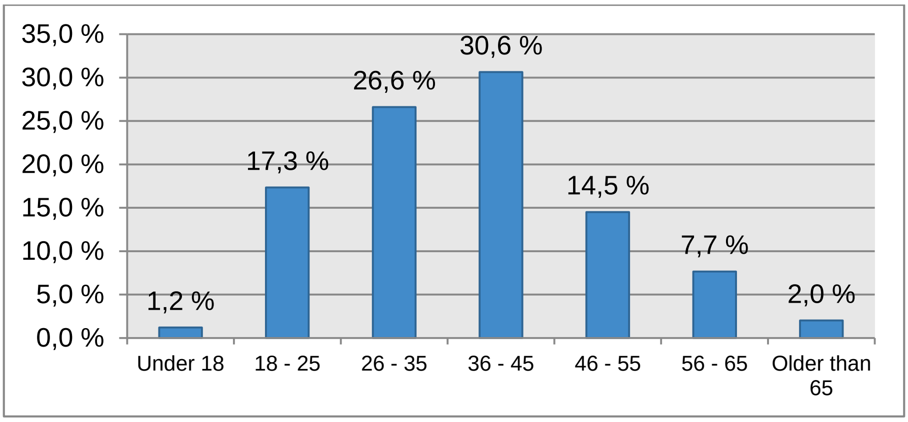

Figure 6.1. Age distribution of the survey sample

Out of the 248 participants, only 15 (6,0%) said they own a PMD. The same 15 participants were the only ones to say they had good prior experience with PMDs. 24,6% have tried driving a PMD once or twice, 36,3% have only seen them before and 33,1% have no prior experience at all. This means that from our sample, approximately 3 out of 10 participants (30,6%) have tried a PMD at least once. See Figure 6.2 for details.

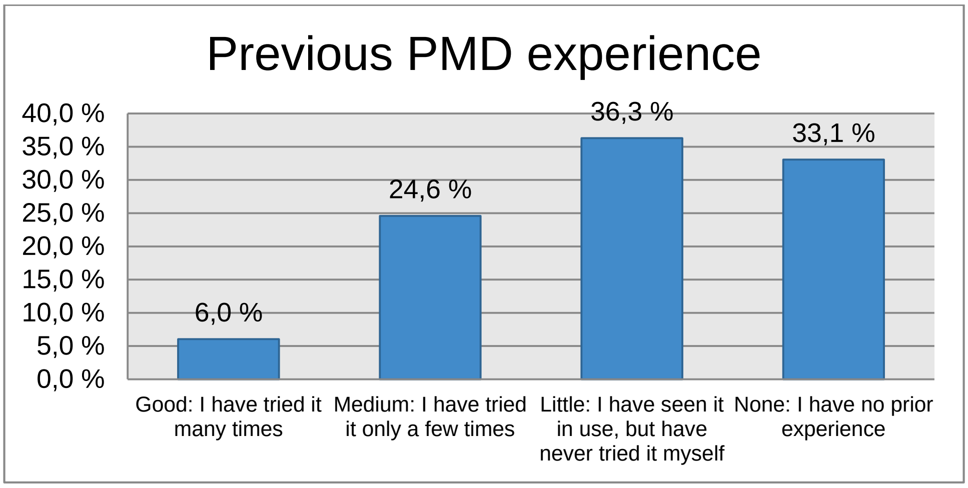

Figure 6.2. Distribution of previous PMD experience

Next, when it comes to Segway use, 13,7% could see themselves using a Segway on a daily basis. 7,3% don't know whether they would use a Segway, while 78,6% said they would not. Only one respondent in our sample was already a Segway user. E-bikes show quite different results. 51,6% said they are positive to using an E-bike for their daily transportation needs, compared to 32,7% negative and 13,7% unsure. 2,0% are currently E-bike riders. The perception of electric scooters seems to be somewhat similar to the Segway, with 19,0%, 69,4%, and 10,9% for *yes*, *no*, and *don't know* respectively. Only 0,8% of the participants are currently using electric scooters.

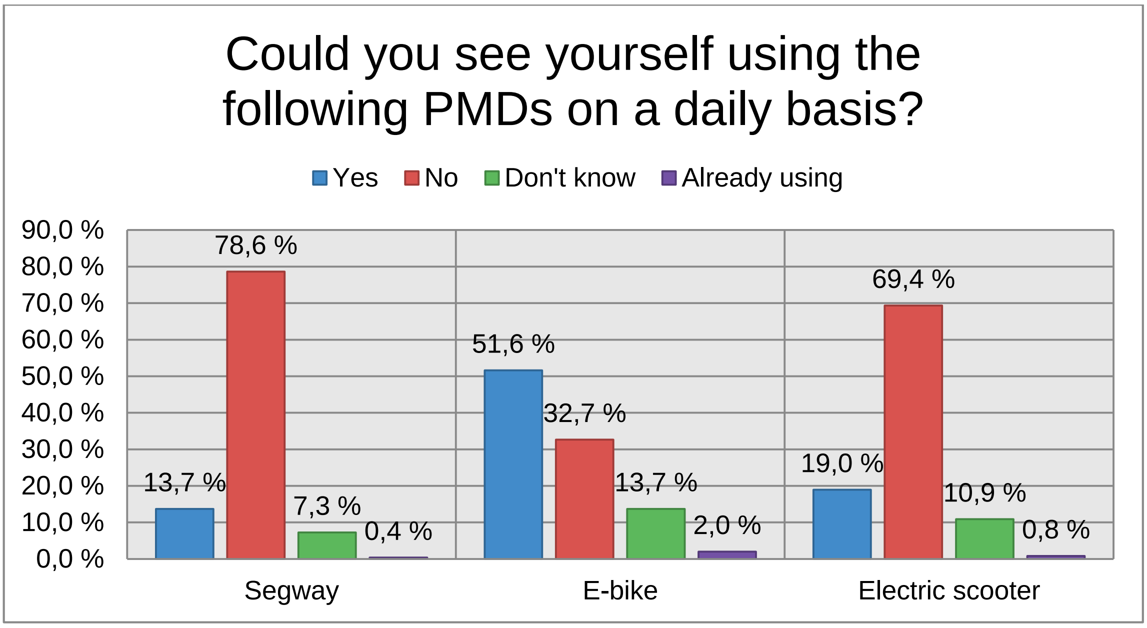

Figure 6.3. Distribution of participants that could see themselves use a Segway, e-bike or electric scooter daily

6.1.1 Device specific results

We will now present the results for each device type. The full results for each device are summarized in Figure 6.4 and Figure 6.5 for positive and negative cited attributes respectively. See Appendix A for detailed results for each device.

Segway

Out of the participants who were positive to using a Segway daily, the two main reasons were ease of use and the fact that it can replace other means of transportation (such as cars or public transit), cited by 60,0% and 57,1% of the participants respectively. Beyond this, the other most common reasons were *range*, *environmental* and *speed*, with 28,6%, 22,9% and 20,6% respectively, closely followed by *size and weight* (17,1%) and *how I'm perceived* (14,3%). Interestingly, none of the participants found the price of the Segway to be a positive attribute, and only 2,9% found the Segway's safety to be a positive attribute.

People who were negative or unsure, for the most part, list a completely different set of attributes. *Price* was by far the most important with 68,1% of the participants listing this as a reason. Next was *how I am perceived* highlighted by 44,6%. 38,5% of the participants who are negative or unsure about the Segway said they prefer to use alternative transportation. *Size and weight* was listed by 28,2% and *safety* by 23,9%. The rest of the attributes were of less importance to the participants. See Figure 6.5 for details.

The *Other* option allowed the participants to express themselves in free text to give a more qualitative explanation for their why they liked or disliked the device. All positive reasons were related to the enjoyment of riding a Segway, while there was quite a wide array of negative reasons, some of which were quite specific such as *"It can't drive up my gravel driveway"* or *"Where should I put my shopping bags?"* Some topics were frequently brought up, however. The first was related to the device and/or riders appearance while riding (which "How I am perceived" was also meant to cover) such as *"It's a little too conspicuous"*, *"Looks damn pathetic. Gets my blood boiling"*, *"You don't look so smart, to put it nicely"* or *"Looks completely ridiculous"*. The other was related to health. Many expressed how riding a bike or walking would benefit your health, and they did not like how passive the rider becomes on a Segway. Some examples of this were *"Segway provides no exercise, which I need"*, *"I find it nice to walk on shorter distances"* or *"Better to use muscle power on a bike"*. Other reasons that were given by several participants were that it seemed too large for a sidewalk yet too small or slow for a roadway, and that a bike was generally more practical.

E-bike

The e-bike acceptance was considerably higher than both the Segway and the electric scooter. Similar to the Segway, the most frequent positive e-bike reasons were the fact that it replaces alternative transport, closely followed by ease of use. The other most frequent reasons were range, speed and environmental, but all remaining options were listed by over 10% of the participants so their opinions were fairly diverse on this issue.

The reasons why people don't want to use an e-bike are more unambiguous. People mostly prefer to use other transportation methods, and they are negative to e-bike prices. Beyond this, the only noteworthy reasons were how they are perceived by others and the size and weight of the vehicle, getting 16,5% and 15,7% respectively.

The *other* category was very high with 33,0%, indicating that many participants did not feel like the other options covered the reasons for why they disliked e-bikes. By far the majority of reasons in this category were that e-bikes are not necessary because normal bikes are *"good enough"*, and provide exercise to the rider while traveling. This is an interesting perspective on PMDs that we will return to in the analysis.

Electric scooter

The main positive reasons for the use of electric scooters were *size and weight*, *ease of use* and *price*. The lowest scores were given to *safety* and *range*. *Other* attributes were either related to portability and the enjoyment of riding.

Negative attributes were most frequently cited for *I prefer alternative transport*, *how I'm perceived* and *safety*. *Environmental*, *speed*, *ease of use* and *size and weight* were all rarely cited as negative. *Other* attributes were quite diverse, but the most frequently cited reason was that participants preferred other means of transport, usually normal bikes. Other common reasons were lack of exercise and that the participants found it better suited for young people, or in general unpractical as a means of transportation.

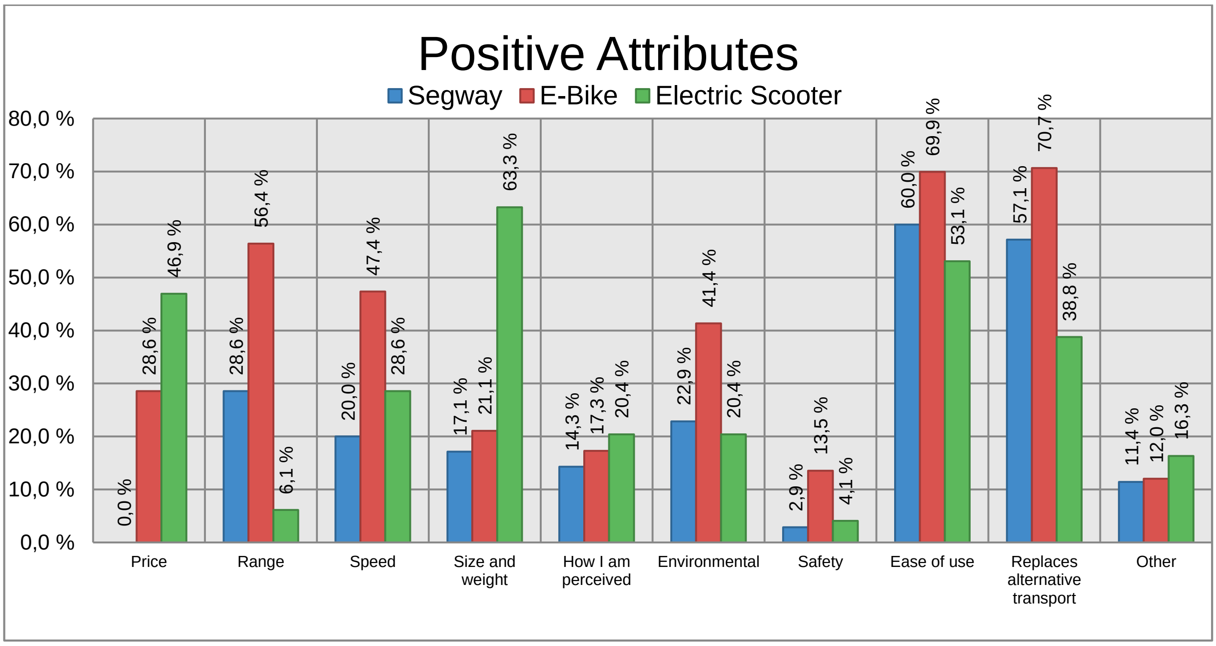

Figure 6.4 Positive cited attributes of Segway, e-bike and electric scooter

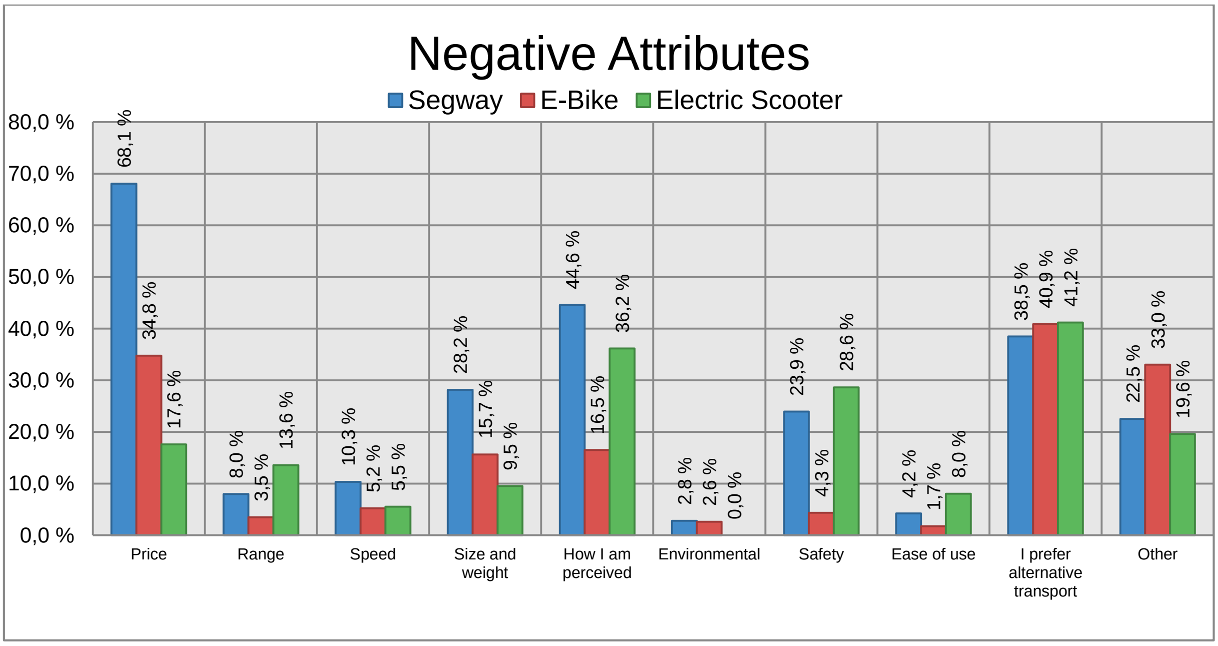

Figure 6.5 Negative cited attributes of Segway, e-bike and electric scooter

6.1.2 Alternatives to PMDs

The final question of the survey asked which modes of transport they typically use instead of PMDs over short distances (see Figure 6.6). *Walking* was the most frequently cited with 73,4%, followed by *bike*, *public transportation* and *cars* with 53,6%, 44,8% and 41,1% respectively. Finally, we have *other* at 5,2%, which included motorcycles, PMDs and electric cars, and scooter / moped with 3,2%.

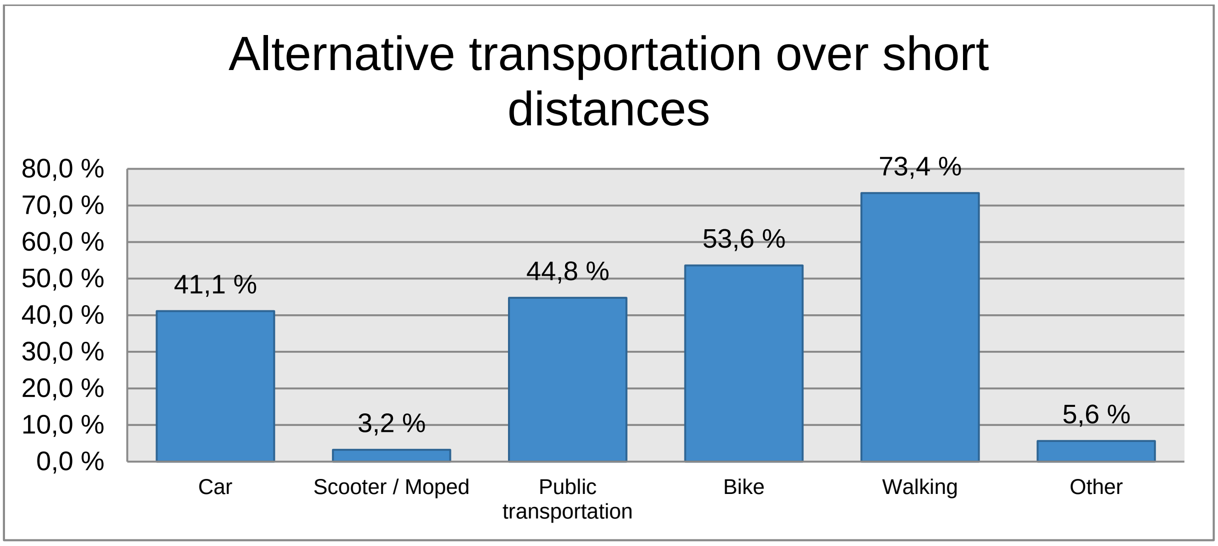

Figure 6.6 Answers to "What method of transportation do you typically use instead of PMDs on short distances?"

6.1.3 Attitude towards PMDs by PMD experience

The opinions of people with more PMD experience will arguably be more valuable than those with less experience, and therefore it would be interesting to see if there was a difference in the acceptance of using the three PMDs based on the participants experience with PMDs. In short, is there a correlation between PMD experience and willingness to use a PMD? From our results, this seems to be the case, as can be seen in Figure 6.7 showing the combined willingness to use either the Segway, E-bike or Electric scooter based on what the participants reported as their previous PMD experience. Those with more experience are more accepting to use any of the three PMDs.

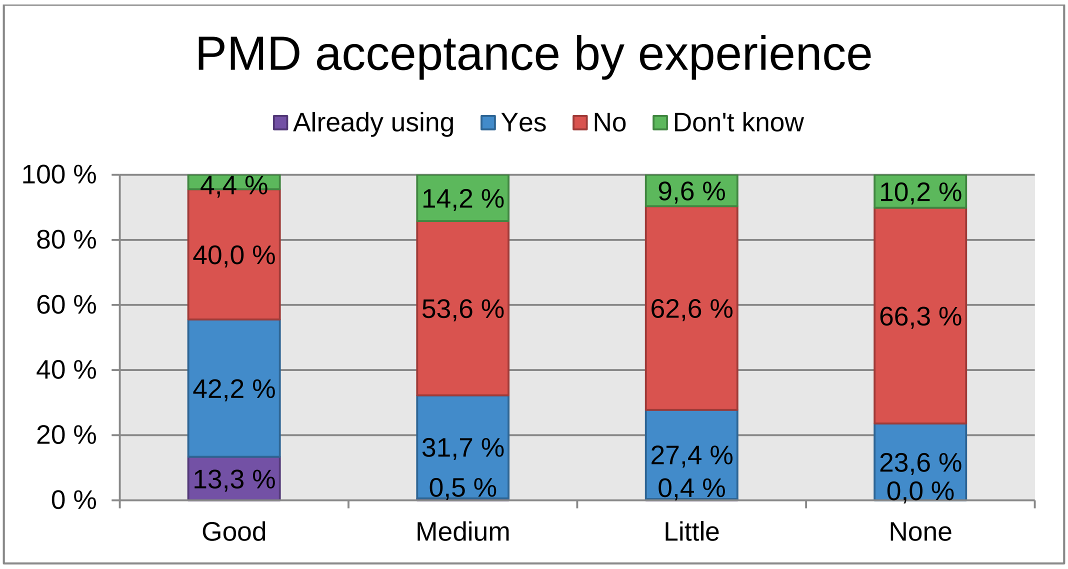

Figure 6.7 Willingness to use any of the three PMDs grouped by reported PMD experience

6.1.4 Attitude towards PMDs by gender

Another topic of interest was determining if one gender is more positive towards PMDs. The participant sample of the survey was highly skewed towards males, which could potentially indicate that men are more interested in PMDs compared to women. However, the results do not show this. When asked if they would want to use a PMD for daily transportation needs, there is virtually no difference between the genders in the answers provided, as shown in Figure 6.8.

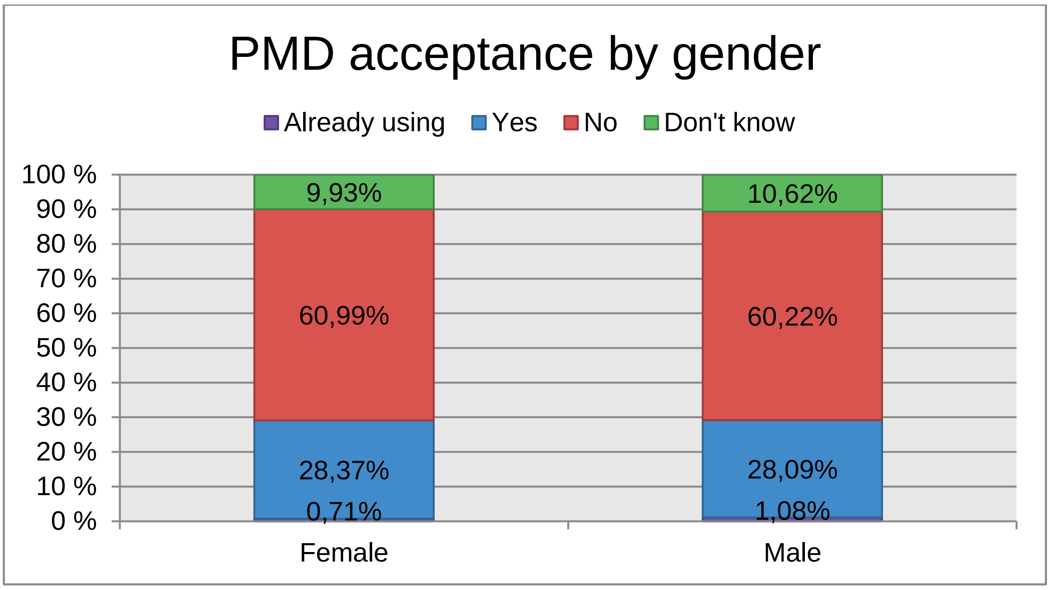

Figure 6.8 Willingness to use any of the three PMDs grouped by gender

6.2 Evaluation of published transport research

6.2.1 Report on Norwegians attitude toward E-bikes

In the report *E-bikes – who wants to buy them and what effect do they have?* (Fyhri & Sundfør 2014), the authors investigate who the typical e-bike customer is, how e-bikes can help increase the use of bikes and reduce the use of cars, and in what way e-bikes can help overcome peoples' barriers to bikes. The study was conducted using a web survey with 5466 respondents. 61 of these were randomly selected to try an e-bike for two or four weeks, and their daily travels and experiences were compared to a control group consisting of 160 participants.

Reasons for low bike use

In the survey, the participants were asked what factors prevent them from using bikes more often. We discussed some of the possible issues related to bikes as transportation in the introduction (on page 7), such as rider physique requirements, travel distance, incline, fatigue and sweat. The report confirms that these obstacles are real issues, as 22% of participants consider bikes too physically demanding, 18% think that the hills are too steep, and 14% highlighted sweat or the lack of a shower following transport as an issue. These conditions, along with the need to transport someone or something, which were cited by 17%, were together mentioned by 56% of the participants, and are highlighted as the issues that can potentially be solved by e-bikes in the report (Fyhri & Sundfør 2014, p.6). Some factors, however, were mentioned even more frequently, such as the lack of good bike roads, safety concerns and bad weather, cited by 46%, 40% and 34% respectively. Other issues brought up were the lack of safe parking options cited by 8% and the need to use a car at work, cited by 15%.

Who is the e-bike customer

When asked if they would consider an e-bike if they were to buy a bicycle today, the participants were roughly divided in three groups. One third were interested, one third were doubtful and one third rejected the notion all together. Women were slightly more interested than men (33% to 25%). Only 6% said they would 'absolutely' consider an e-bike.

Interestingly, the group most interested in acquiring an e-bike consists of people who currently cycle little or very little (0.1 to 10 km per week). This indicates that e-bikes to a small degree will replace normal bikes, but to a large degree replace other means of transport.

E-bike knowledge

Over two thirds say they knew little or nothing about e-bikes, and 27% say they knew 'some'. Only 5% said they knew much or very much about e-bikes. Their knowledge was then tested by being presented with a list of 6 claims about e-bikes and then having to determine if the claim was true or not. The authors found there was a good correlation between the participants' perception of what they knew and what they actually knew ($r=0.44$, $p<0.0005$).

How do e-bikes change the distribution between different modes of transport?

The participants were asked a series of question to identify their bike use and daily travels. By comparing the before and after data the authors could determine if bike use increased as a result of the experiment, and at the expense of what modes of transport. Furthermore, since the control did not receive an e-bike, the authors can say with great certainty that the change was a result of the e-bike and nothing else. The percentage of people in the test group who had cycled on the day before the experiment was 30%. This percentage increased to 52% by the situation. In the control, this percentage was 24 before the experiment and 20 after. Cycling as a share of all travelled kilometers was 20% both before and after the experiment in the control group, but increased from 28% before, to 48% after in the test group. This transition occurred primarily in the form of less public transport, but also car trips decreased as a result of the experiment.

6.2.2 Market research on bikes in four Norwegian cities

This report is part of a larger project to suggest targeted bike measures in four cities in Norway. While the project is focused on identifying effective measures to increase bike usage, the report also includes a survey on peoples' bike perception and provides an insight into why bikes are not more common in Norway. The survey was conducted online and had a total of 4210 respondents from the four cities.

Bike activity

One of the goals with the survey was to estimate the level of bike activity in the cities. The participants were asked how often the use a bike at the current time of year (the survey was conducted in October). The results show that quite a lot of people report high levels of bike use, with 40% saying the use the bike several times a week, 23% say they cycle weekly or monthly, and 35% say they rarely or never use a bike. The authors point out that because the topic of the survey is about bikes, it can be expected that participants who are already positive to bike use are more likely to respond.

The average bike trip

The average bike trip is 28.2 minutes and 9.6 km long, but this is a result of many long and many short travels. 40% of travels are less than 15 minutes, 36% between 16-30 minutes, and 26% are over 30 minutes. In other words, most travels are short, but one fourth of the trips are long travels of more than 30 minutes. By far the most common travel purpose for bike travels is work and school with about 60% of all trips. All other travel purposes share the remaining 40% somewhat equally (These purposes are: purchases, recreational activities and others).

The average cyclist

The authors found that men are more likely to bike often (at least once every 14 days) than women with 62% and 54% respectively. However, they also found that women are increasingly more likely to cycle often in areas with higher levels of bike use. People aged between 35-54 years is the group with the highest percentage of frequent cyclists with approximately 65% of participants cycle at least once every 14 days. The oldest (65 and up) and youngest (18-24) groups in the survey cycle the least with 50% and 47% respectively.

Reasons for not using a bike

Identifying why bikes are not more common is important if we want to understand how PMDs will supplement existing means of transportation. If, for instance, the only reason is bad weather then PMDs will not do much to improve the situation. The results show that most people don't use a bike because using a car is easier. In total this constitutes 35% of participants who rarely or never use a bike. Issues related to infrastructure and safety makes up 26% and 22% respectively. The least important reasons were fear of theft and "I'm in bad shape" with 8% and 7%. The other category constituted 29% and contained many different reasons, but most were related to practical issues such as bad weather or health issues (see Loftsgarden et al. 2015, fig.S.3 for all results).

6.2.3 Norwegian National Travel Survey 2013/14

The report is the last of seven national travel surveys to map out Norwegians travel activity and travel patterns. Approximately 60 000 persons from 13 years and up have been interviewed about their transportation habits.

Travel Distance

The average distance for a single trip is 14,5 km and 47,2 km for a full day, divided by 3,26 trips. The majority of trips are short, with 39 % being less than 3 km and 72 % less than 10 km. Only 15 % are over 20 km. This means that the vast majority of trips are well below the limits of what PMDs can provide.

Average distance and number of daily trips by means of transport

If we look at the distances and number of daily trips for various means of transport, we find that 55 % of all travels are carried out as a car driver and 8 % as a car passenger. This means that 63 % of all trips happen in a car, and at least 85 % of car trips (47 out of 55) takes place without any other passengers. The average distance for a car trip is 15,8 km over 1,78 daily trips as driver and 21,7 km over 0,28 daily trips as passenger. Bikes account for only 5 % of trips with an average distance of 5,1 km per trip with 0,15 trips per day. Public transit has a 10 % share with 35,6 km, and 21 % and are by foot with 2,2 km. The remaining 1 % comes from MC and others.

Means of transport for various distances

For distances under 1 km, walking is, unsurprisingly, the dominant mode of transport with 68 % of trips, but even at such short distances cars also have a notable share of 24 %. For the 1 - 2,9 km range, most trips (59 %) are carried out by car. 29 % of trips are on foot and 8 % by bike. At these distances public transit has not yet reached significance with only a 3 % share. On 3 - 4,9 km public transit reaches its overall national average of 10 %, and at these distances cars are used in 69 % of trips. Bikes are used slightly less with 6 % and walking accounts for 14 %. For distances longer than 5 km the trend continues with cars being increasingly more common at the expense of walking and cycling. Public transit also increases slightly at longer distances, although not as much as cars (see Hjorthol et al. 2014, fig.5.1 for details).

Work and school trips

Since transportation to work and school is a potentially common use case for PMDs, these trips are of particular interest, accounting for 26 % of daily travels of people aged 13 and up. Of average we find that walking is less common for work trips, while all other means of transport are slightly more common. School trips on the other hand are dominated by walking and public transit. Bike and car passenger are also more common choices, at the expense of car driver and MC. Table 6.1 list the means of transport for work and school trips compared to the overall average.

Table 6.1. Means of transport distribution between work, school and any purpose trips

Means of transport	Work	School	Any purpose
Walking	11 %	31 %	31 %
Bike	7 %	10 %	5 %
Car driver	62 %	11 %	55 %
Car passenger	3 %	8 %	8 %
Public transit	16 %	37 %	10 %
MC /Other	2 %	3 %	1 %

6.2.4 Overview of results

From the research presented above, Table 6.2 presents a summary of the most relevant for the project. These results were used as validation and extension of the survey results in the analysis below. Table references: [1] Report on Norwegians attitude towards e-bikes (Fyhri & Sundfør 2014), [2] Market research on bikes in four Norwegian cities (Loftsgarden et al. 2015), [3] Norwegian national travel survey 2013/14 (Hjorthol et al. 2014).

Table 6.2. Overview of results from the evaluation of published transportation research

#	Results	Reference
1	Main reasons for low bike use: Easier to use a car, Fatigue related issues (distance, incline, lack of shower), and infrastructure related, including safety concerns.	[1], [2]
2	People who do not currently use a bike are more interested in acquiring an e-bike.	[1]
3	Increased e-bike use will be at the expense of public transport first, and cars second. Normal bike use will not be significantly reduced.	[1]
4	Two thirds know little or nothing about e-bikes, suggesting that knowledge is a major obstacle in increasing PMD use.	[1]
5	40 % report riding a bike several times a week (during autumn), but only 5 % of trips are by bike.	[2], [3]
6	35% rarely or never use a bike (during autumn).	[2]
7	The vast majorities of bike trips are for work or school purposes (60%), where bikes account for 7 – 10 % of all trips.	[2], [3]

#	Results	Reference
8	The age group with the most frequent cyclists is 35-54 years, and especially men. The least frequent group is 18-24 years.	[2]
9	Car is the dominant mode of transport for all travel distances in Norway, except distances of less than 1 km.	[3]

Some of these results in Table 6.2 are related to the online survey. For example, similar to result #4 we found that 69 % have little or no experience, and we have shown that those with more experience are more willing to use PMDs. Additionally, compared to result #9 we found a similar result where 41,1 % say they typically use cars for short distances.

6.3 Analysis

In this stage we have conducted a needs analysis to identify needs and wants in the prototype. We will now present our analysis for the data collected in the online survey and the statistical evaluation.

6.3.1 Target group

By looking at which age groups that are the most positive to PMDs in our survey, we see that only 3,3% people over the age of 45 could see themselves riding a Segway or electric scooter, compared to 25% in the group 45 and younger. This suggests that a target group for our prototype should probably aim for the lower age groups and especially the groups below 45 years. If we include e-bikes, the results are less clear as e-bikes have a much higher acceptance rate in all groups. However, to assume that e-bikes could share this aspect with other future PMDs is problematic, because the e-bike has a similar form and operation to ordinary bikes meaning they have an advantage over other PMDs in this regard. E-bikes are also sometimes marketed to the elderly in particular, as the added pedaling assistance is especially useful to people with limited mobility. Because of this, relying mainly on the acceptance rate of the Segway and electric scooter is probably a better approach if the purpose is to limit the target group.

Further, drawing on result #2 and #3 from the transportation research evaluation, the data suggests that those who do not already use bikes for transportation are more likely to get an e-bike, so it is possible that to further narrow down the target group to those who are less likely to ride normal bikes is preferable. Result #8 shows that this group is mainly men between the ages 35 - 55, so a target group up to the age of 35 years is an additional option that should be considered.

We also looked for a difference in PMD acceptance between males and females, but from our data there appears to be no difference, so we have no empirical reason for targeting the prototype specifically towards one gender. It should however be pointed out that the responses were predominately received from men, so the validity of this result is questionable. The fact that more men responded could, for example, indicate that females are overall less interested in PMDs, but this is of course pure speculation.

To summarize, it would be beneficial for the prototype to target both men and women with a short distance transportation need (such as in an urban environment) between the ages 16 - 45 and perhaps especially under the age of 35.

6.3.2 Prototype attributes

Price

While price is definitely one of the less important aspects of designing our prototype, it will be mentioned briefly and used to make sure the technology and production of the prototype does not exceed a price range of what people are willing to accept. With price, Segway is the clear looser where almost 70% of people consider price a negative attribute, and 0% consider it positive, but even e-bikes get more negative ratings than positive. The only category where a larger percent of people find the price to be a positive aspect is with electric scooters, suggesting its price range is what should be targeted to maximize adoption rate.

Range and speed

The range attributes is interesting because even though many people cite range as a positive e-bike attribute (56,4%) and very few did the same for electric scooters (6,1%), range is actually not rated very negatively for any of the device types. In other words, people like a long range, but don’t seem to mind when the range is not as high. Of course, this is only true within certain limits, and we don’t know how the situation would look with a lower range than electric scooters, but it seems that a range of 10-30 km is sufficient for most people. With speed the situation is similar except here the Segway is at a disadvantage. The Segway scores less positive on speed, but only 10% think the speed of the Segway is a problem. This suggests that both range and top speed will be of lesser importance in the prototype.

Size and weight

According to the results, size and weight is the electric scooters’ most highly rated attribute with 63,3% positive and only 9,5% negative. The E-bike got a fairly neutral score (21,1% positive to 15,7% negative) while the Segway, which weighs about 50 kg, scored the worst of the three devices, so this suggests that people consider a low size and weight important in a PMD. This was expected, as it implies a PMD that, for instance, can be carried which greatly increases the mobility of the vehicle and this makes it possible to combine it with other means of transportation like public transit. It would also make it possible to carry it inside buildings and make urban obstacles such as stairs or raised curbs less of a problem.

Self-perception

The results clearly show that the participants did not like how they are perceived (or at least, how they *feel* they are perceived) when riding a Segway or Electric scooter, but few of the participants said the same about E-bikes. I've often heard the complaint that *"Well, you look like an idiot on that thing"*, regarding the Segway, so this was expected. Some may even say it has even become popular to hate Segway riders for the way they look. Many of the comments received both in the survey and in the online discussions, indicate that this is indeed a common criticism as a lot of people seem to think Segway riders are too lazy to walk, even though the same logic could apply to all forms of motor powered short distance travel, including cars. The main difference seem to be that on a Segway it appears like you are not putting in any effort compared to the other travelers on sidewalks or bike roads. Regardless, this is likely an obstacle to people who genuinely see the value in a device like the Segway and want to use it over a car. The uniqueness and eye-catching design seems to also be a disadvantage, as a lot of people don't want to stand out from the crowd, regardless of perceived effort.

Interestingly, 'How I'm perceived' also scored comparably negative when it comes to Electric scooter (although not as much). This was somewhat of a surprise, as normal non-electric kick scooters can be seen fairly frequently in urban areas, and you would think that people would be ok with riding an electric powered version. But to be fair, most electric scooters intended for adults are indeed significantly larger and more rigid than kick scooters. This is in contrast to the E-bike which in many cases looks mistakenly similar to normal bikes. Because of this, people are not worried at all about how they're perceived on an E-bike, as it simply looks like they're riding a normal bike.

In short, the prototype should probably look as similar as possible to a human-powered transportation device, and also have a design that encourages some form of body movement to make it look like effort is required.

Environmental issues

Regarding environmental benefits it is clear that people agree that PMDs are good environmental measures and hardly anyone cited environmental as a negative point on any of the device types. E-bikes scored better than the other two however, likely because it is not only electric but also human powered, thus more energy efficient. This probably won't have much of an implication on the prototype, other than the fact that people realize the environmental benefits of PMDs and if the device can be used with human power it is an added bonus.

Safety

In terms of safety, e-bike is the clear winner. Both of the other devices score considerably lower on safety, and suggest that the safety of a PMD is an issue that people care about. The fact that the other two devices were assessed as less safe than the e-bike does not necessarily mean that they are, but this is largely irrelevant in this context. What's important to note here is that people *assess* the devices to be unsafe which means that safety is a valid and important concern in PMDs that needs to be addressed in the prototype. Safety is an issue that increasingly becomes a problem as the devices get smaller and the speed gets higher, so features such as speed-limiting, a good braking system, head lights and tail lights, electronic safety measures, etc. are some of the features that should be considered in the design of the prototype.

Ease of use

All devices get good scores when it comes to ease of use, but e-bikes are clearly assessed as the best in this regard and almost 70 % of people think ease of use is one of the most important aspects of e-bikes. In comparison, electric scooters score 53,1 %, but all devices receive low negative scores on ease of use. So overall people assess ease of use as quite good, but at the same time, 7/10 responders report never having tried a PMD so most of them lack the experience really needed to assess this. Regardless, it shows that ease of use is not a limiting factor for current PMDs and therefore poses no additional ease of use requirements on the prototype.

6.3.3 Alternative transportation

The option "I prefer alternative transportation" was fairly consistent across the device types cited by about 40 % of the participants for all three types (Figure 6.5, page 56). But to better understand the implications of this result, we need to know not only *which* means of transportation they prefer, but also *why*. To answer the first question, let us first turn to the next survey question on PMD alternatives.

Which means of transportation do people prefer on short distances?

The results show that as many as 73,4 % of the participants say they typically travel on foot, 53,6 % by bike, 44,8 % by public transport and 41,1 % by car (Figure 6.6, page 57). This corresponds reasonably well with the result that 40 % of people report riding a bike several times a week, as shown in transportation research result #5 (Table 6.2, page 62). However, when looking at this in relation to the statistics of Norwegians transportation habits, there seems to be an inconsistency, namely that only 5 % of trips within cities are by bike. Additionally, half of trips are by car, 27 % are on foot and 14 % with public transportation. In smaller towns, the car percentage increases quite dramatically, up to 74 % for the urban areas with a low number of inhabitants at the expense of all other modes of transport (Engebretsen & Christiansen 2011, p.20). While this could suggest that people over-estimate their own bike use, it is also possible that the data is correct and that over half the sample does indeed use a bike frequently, just that they use other means of transportation so much more that the resulting overall bike share is 5%. It is also possible that the participants in the survey misinterpreted the question text. The term "short distance" was defined as distances up to 20 km in the intro of the survey, but it was not restated in the question text. Because of this it is possible that the ambiguousness of "short distance" caused the participants' to think of this as something considerably less than distances up to 20 km, which actually covers the most of Oslo[3]. To travel only 10 km by foot would take over 2 hours (Google 2005) and it seems highly unlikely that over 70% of Norwegians would be willing to spend that much time if faster transportation options were available. This is further confirmed by result #9 that shows that for distances 1 km to 20 km and higher, car is the dominant mode of transport with at least a 59% share.

Why do people prefer these means of transportation?

Next, we will look at why people prefer these alternatives on short distances. The data gathered on this issue is limited and is in relation to bike use, i.e. reasons for using something other than a bike for various trips (Result #1 in Table 6.2, page 62), but the data nonetheless provides an insight to this question. According to Loftsgarden et al. (2015), the main reason for low bike use is that it's easier to use a car, while Fyhri & Sundfør (2014), found various fatigue related reasons to be major obstacles. This suggests that, for situations where a bike could have been used, people prefer cars over bikes largely because of the low amount of effort required. This seems like a good argument for PMDs in general, since they require less effort than bikes without the same problems that derive from car use that was described in Chapter 1.2. Other important issues found by both authors were infrastructure and safety concerns. Infrastructure and safety are obviously closely related to each other, and some would argue this is a chicken or egg problem where increased governmental focus on bike infrastructure becomes more important as the infrastructure is needed (Schmitt 2012). As PMDs and bikes use the same infrastructure, it could be argued that the adoption of PMDs will indirectly lead to better infrastructure, and thus better safety, for both bikes and PMDs.

6.3.4 Prototype Requirements

The following requirements (Table 6.3) were formulated on the basis of the analysis from stage 1. As UCD encourages the possibility of changing requirements, these were subject to change throughout the design life-cycle as new needs were discovered. The requirements are also classified as either functional requirements (FR) or non-functional requirements (NFR) in the table.

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[3] For example, the distance between Alna on the east side of Oslo to Bærum on the vest side is approximately 20 km (Google 2005).

Target group: Men and women aged 16 – 45 and especially 16 – 35 with short distance transportation needs, primarily in urban areas.

Table 6.3. Summary of the results of the needs analysis with the implications this brings for the prototype

#	Topic	Needs analysis	Requirement Specification
1	Price	Price is currently too high. Should be similar to electric scooters.	Price of components must allow a production equivalent to have a cost similar to electric scooters. NFR
2	Battery / Range	Current vehicles have sufficient range.	No explicit requirements. Battery must be sufficient for testing only: Approximately 1 hour of light use. FR
3	Speed	Current vehicles have sufficient speed.	No explicit requirements. Top speed must be sufficient for testing only: Approximately 10-15 km/h. FR
4	Size and weight	Size and weight is currently an issue. Should be as low as possible.	Low weight is required. Aim: less than 10 kg. Size must be small enough to allow for easy carrying and bringing inside buildings. NFR
5	Design	Self-perception is a concern in current vehicles, especially when the rider is perceived as passive. Does not apply to e-bikes.	'Stealth' (I.e. should look like a human powered vehicle), encouraging body movements while riding. NFR
6	Energy use	Electricity is considered environmentally friendly. The possibility of riding using manpower is appreciated.	No explicit requirement beyond being fully electric. NFR
7	Safety	Safety is a concern in current PMDs.	Measures to improve safety are required. Safety specific features should be considered. NFR
8	Ease of use	Current vehicles have sufficient ease of use.	Covered by the theoretical framework. No additional requirements. NFR

6.4 Reflection on stage 1

In the first stage of the design life-cycle, data was collected through an online survey and existing transportation research. As mentioned in Chapter 5.3, choosing quantitative methods for the needs analysis was a very conscious move because these methods allow capturing the needs of a diverse group of people much more easily. The purpose of the needs analysis was to understand not only the users' needs, but also the context of use. Other common methods to gather requirements include interviews, observations, and some of the methods applied in later stages, such as focus groups, brainstorming and prototyping. An observation would probably not be particularly useful in this case, primarily because it is not suited to answer ‘why?’ questions or capture attitudes and opinions. If applied, however, an observation study could be on how people get around in urban environments today to identify problems or opportunities, or about how people interact with current PMDs. In this particular instance, neither of these approaches seems ideal and talking to the participants to understand their needs and their troubles would probably reveal results that are more relevant. If a person does not cycle because of safety, or does not drive because of parking, they are likely to choose an alternative where one is available, and this information is lost in an observation study.

Interviewing of a domain expert, on the other hand, was one of the methods that were highly considered for Stage 1. A request was sent to TØI to be directed to a person with PMD expertise, but unfortunately, the only person with such knowledge lacked any PMD expertise beyond E-bikes and because of this did not wish to participate in the interview. A search for another domain expert proved unsuccessful, but this is not terribly surprising considering the current legal situation of these vehicles. With a domain expert interview, the goal would have been to get a better contextual understanding of how these vehicles fit within the current urban transportation landscape and to concretize the main challenges with current vehicles. Another method that was highly considered was a usability test of an existing balance-controlled vehicle, such as a self-balancing unicycle. The plan with this method was to invite a small group of people to participate in a test and see if they could complete a set of pre-defined tasks. Follow-up discussions might have revealed informed and valuable needs from a group of people who had just tested a PMD for the first time. This method was also dropped after getting access to such a vehicle and a testing area at little to no cost proved difficult. Additionally, almost everyone asked to participate declined participation, often saying that it *“looked a little too scary”* to ride a self-balancing unicycle.

6.4.1 Needs analysis validity

One of the most important things to note about the online survey validity is that the participant pool consisted mostly of male respondents. This was largely a result of the recruitment process that relied on online forums, where young males are overrepresented, and mailing lists at work, with predominantly middle-aged males as recipients. Consequently, the lack of respondent diversity means that the survey results do not cover the entire user group. No significant difference between males and females in terms of willingness to use PMDs for transportation was found through the analysis however. Another point is that since the survey was not addressed specifically to the potential respondents, they may have felt less compelled to respond, and it is possible that those already interested in, or those having strong opinions of PMDs (whether positive or negative) were more likely to respond. As a result, extreme views are probably overrepresented compared to what you would otherwise find in the target group as a whole. Finally, most respondents are uninformed and have little, if any, PMD experience. This may be a problem because it limits the importance of many of the respondents' contributions, and the voices of those who have previous experience may not be heard. If a respondent has never heard of a PMD, they are not in a position to evaluate its attributes because they are uninformed. I would however argue that this is also precisely the case with the target audience, and as such is less of a validity issue. A new PMD design would have to convince people with little to no experience, because this is what most people have.

When it comes to the review of other transportation research, its main validity problem is that is not specific to PMDs. Bikes are repeatedly used as a substitute for PMDs, as they are essentially the same class of vehicle and rely on the same infrastructure. As a result, the data collected provides only a very general and broad insight into the use context, and may not be fully applicable.

7 Stage 2: Design

The following chapter presents the results from the methods used in stage 2 of the design life cycle. Based on the requirement specification from stage 1, we continue into a more exploratory stage when trying to create a design concept and paper prototypes. The focus group, brainstorming and design workshop was part of the same session and is described in Chapter 7.1. This also provided a more qualitative layer to the needs analysis results, which we present in Chapter 7.2. Then we describe the paper prototyping process that follows in Chapter 7.3, which was conducted in parallel and supported by the investigation of similar design solutions, described in Chapter 7.4.

7.1 Focus group and design workshop results

Out of the seven participants, only one had personal experience riding a PMD (during a Segway sightseeing tour), but all others were familiar with PMDs as a concept. In general, all participants were in agreement with the results of the survey, stating that the e-bike was the most useful of the three because it operates and looks like a normal bike, and because it doesn't stand out as much as devices with a unique look. One participant said: *"The only one I'd use personally would be the e-bike. The Segway looks like it's for obese or lazy people."* They also considered the e-bike to be the safest option of the three and liked that it can be used even with a depleted battery. *"If the battery runs out on a Segway, I'm basically stuck. If it runs out on an e-bike, it turns into a normal bike"*.

Figure 7.1. Discussing the results from the online survey during the focus group

The participants found the Segway category to be clumsy and impractical mostly because of its large size and weight, making it difficult to transport or use in combination with public transit systems, as well as difficulties related to parking. One participant asked *"What am I going to do with it when I go* *to buy groceries? It's too big to go inside, right?"* The participants all found the Segway to be better suited in specialized tasks and used for in-doors transport of large buildings like airports, shopping malls, hospitals and schools, and agreed that it *"looks way too silly"* for normal urban transportation. Regarding electric kick-scooters the participants were less vocal, but expressed concerns regarding the safety and stability of the vehicle at high speeds. *"Is it really stable at high speeds? I don't think I would feel comfortable going 20 km/h on a kick-scooter."* Otherwise they agreed with the survey results, that the smaller size and weight was a plus, but that an e-bike or normal bike is still a better choice in most situations. They also noted that PMDs in general would probably benefit substantially from better facilitation in the cities, like more dedicated bike roads.

Figure 7.2. Participants are working on their design concepts during the design workshop

The brainstorming stage resulted in a long list of ideas such as electric skateboards, rollerblades, roller skis, snow racers, snake boards and more. Out of this list the participants found the skateboard and rollerblade concepts to be the best fit for the requirements and chose to continue with these in the paper prototyping stage. The participants formed groups and discussed the optimal location of the various components, represented using post-it notes, as they created the paper prototypes (see Figure 7.3). The participants discussed various design concerns as they made decisions, such as initiatives to hide the components as much as possible, keeping the device light weight and distributing the weight equally on the front and back of the vehicle. Some of the groups also made minor alterations to their designs when they saw what the others had created.

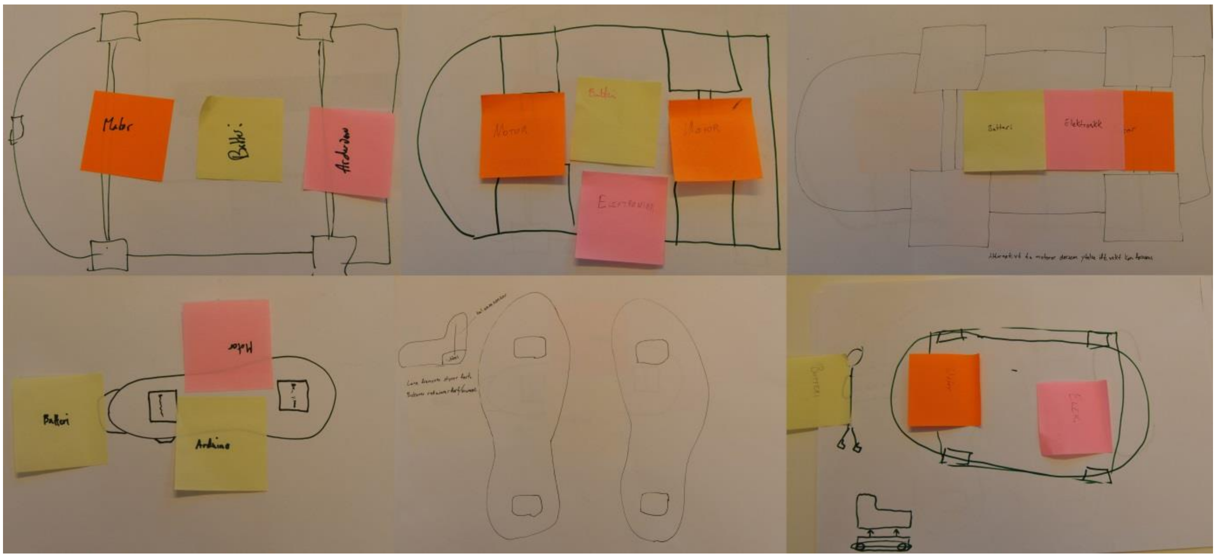

Figure 7.3. Design concepts created during the workshop. Top row: Skateboard, bottom row: roller blades

7.2 Qualitative perspective on needs analysis

In this chapter, we will look at the needs analysis result in light of the focus group perspective to gain a better, qualitative understanding to determine what factors of design are the most important to potential users. Looking at the data from both the focus group together with the data collected in the needs analysis, several attributes have been identified with varying degrees of importance. The results of this inquiry indicate that purely technological specifications like range and speed are not the limiting factors in the adoption of current designs, and neither is ease of use or environmental issues. Instead, the opportunity lies in the more intangible aspects of design like self-perception, mobility and partially in safety. This was further echoed in the focus group discussions in the subsequent stage, but here, additional points were brought forward such as the benefit of being able to use the vehicle with human power alone.

The self-perception issue is an interesting one, but not terribly surprising. Riders of self-balancing vehicles like the Segway in particular seem subject to negative comments of either looking 'dorky' or being lazy. Equally interesting, is the lack of studies on this phenomenon in the literature. Searches for literature on the self-perception of riding PMDs proved unsuccessful, and indicate a potential for expansion in the literature. How can this issue be resolved? Is the problem a result of the devices themselves, the people who are riding, or the people who are watching? Similar descriptions of Segway riders used by the focus group participants, is also found in an essay titled *'The Trouble with the Segway'* by Graham (2009). In the essay, Graham explores the 'collective hate' towards Segway riders and conclude that much of the reason it failed is that it appears like you're not putting in any effort, even though people in other forms of powered transport are not putting in any effort either. The *appearance* of not putting in enough effort seems to be the key. On a Segway, you are seemingly ‘floating’ above the ground while not moving your body. Compare this with pedestrians and the main difference becomes that Segway riders are standing completely still while seemingly accomplishing the same as the pedestrian. Graham then suggests a thought experiment with an alternative design to eliminate this problem where the rider is positioned with one foot in front of the other like a skateboard. With this design it doesn’t appear as effortless, regardless of whether or not the rider is actually putting in more effort.

Graham provides some good points in that a device that encourages a stationary, no-effort stance is not what users want. However, based on the results from the needs analysis I will add to this that it may also be unfavorable for a PMD design to have a unique or eye-catching look, as many people do not want to stand out from the crowd, regardless of the perceived effort.

Vehicle safety was clearly of importance to both participants in the survey and the focus group. Additionally, the statistics studied show that safety, mainly as a result of poor infrastructure, is a major concern for the use of bikes in urban environments. However, it is important to note that this does not necessarily mean that current PMDs are unsafe, especially seeing as very little of the data gathered in both the focus group and needs analysis came from participants with extensive PMD experience. In terms of PMD safety, a study by The Centre for Electric Vehicle Experimentation in Quebec (CEVEQ) evaluated the Segway and electric scooter with a group of 50 test participants, and found that the participants generally thought both vehicles *“felt very safe”* (Lavallée 2004, p.48). Moreover, most participants found the vehicles relatively easy to learn, although steering, reflex actions and getting around obstacles were slightly more difficult on the Segway (Lavallée 2004, p.47). This is consistent with the general agreement identified through the needs analysis where all three vehicles were assessed as easy to use.

Another important perspective was concerned with attributes not specific to the device itself, but specific to the context in which it is used. Based on the related research evaluation, infrastructure is a concern affecting bikes, and these issues, as pointed out in the focus group, will likely effect PMDs as well since they rely on the same infrastructure. It is certainly possible that PMD adoption will suffer in areas where the infrastructure is lacking, similar to how poor bike infrastructure has been identified in the transportation research evaluation as one of the main reasons for not using bikes for transportation.

7.3 Low fidelity prototyping

Low fidelity prototypes are typically used early in the design process as an exploratory design tool, and are particularly useful because they are cheap and easy to make and the need for making design changes can be quickly identified and carried out (Lazar et al. 2010, p.260). A design-oriented research approach requires a certain amount of exploration with different design ideas and concepts, and this process started in the focus group and continued over to the design workshop and now into the low fidelity prototyping stage. Based on the design ideas and concepts from the workshop and focus group, an initial low fidelity prototype was created that combined all these three design sketches into a single unified design to determine the feasibility of building a testable prototype. Ideally, both concepts should have been realized, but this is beyond the scope of this thesis and because of this, one of the two concepts will be chosen for construction and user testing. We will first look at the skateboard concept. The three sketches made by the participants are shown in Figure 7.4.

Figure 7.4 The three skateboard sketches made during the workshop

With the skateboard sketches, neither of the three differ substantially. All of participants placed the battery and electronics under the skateboard deck and between the wheels in their respective sketches. There are some differences in terms of motor placement and one sketch uses two motors, but otherwise the differences are minor. All concepts further described a similar balance interface where leaning on the front and back of the board controlled acceleration, and only differed in what kind of technology to use. We started working on a unified design by creating a simple first iteration paper prototype, which was deliberately completed before the investigation of similar solutions was carried out (described in Chapter 7.4, p.79). This ensured that we avoided becoming too influenced by the design of current solutions. The first iteration skateboard prototype can be seen in Figure 7.5.

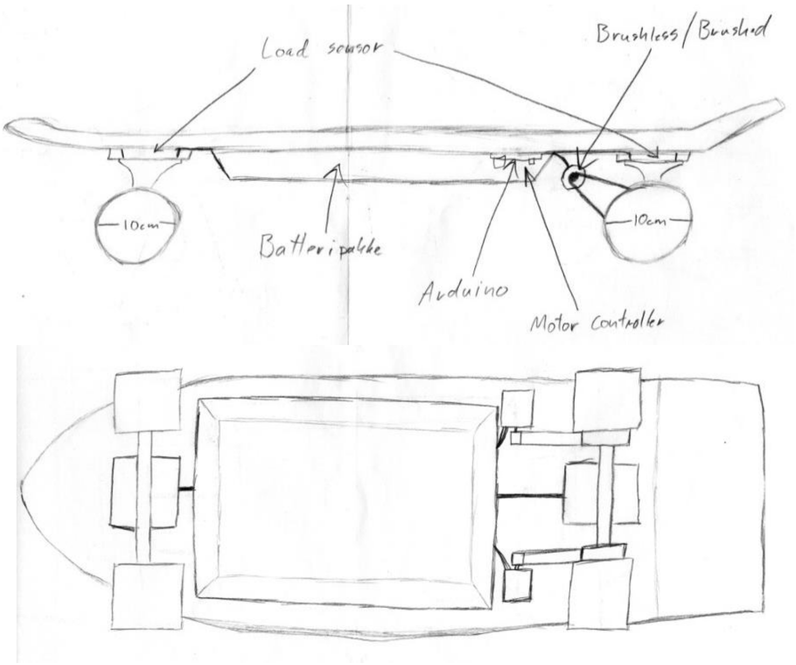

Figure 7.5 First iteration paper prototype of the skateboard concept

With this, the fidelity was slightly increased compared to the sketches. Dual motors were selected as there is limited space under the deck, and we were unsure if a single motor of this size would be sufficient. The motors were both placed in the back, contrary to one of the sketches, primarily because less space is used, allowing for a potentially larger battery. The interface idea was simply to use two bathroom-scale type weight sensors on the front and back of the board to detect the weight distribution changes between the feet.

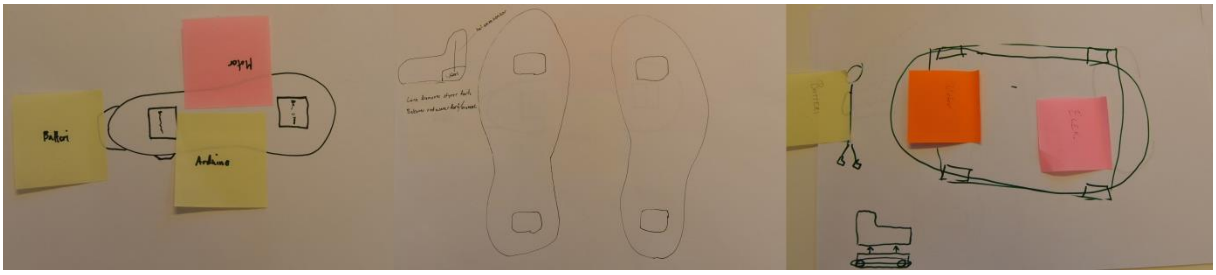

Figure 7.6 The three roller blades sketches made during the workshop

Next, we will look at the roller blades concepts, which can be seen in Figure 7.6. These concepts were a little more diverse. One showed an interesting design that included a shoe with a detachable propulsion unit and a battery located inside the users' backpack. Another had its battery running up from the heel along the back of the foot, and the final had everything integrated, but with a detachable battery for easy battery swapping. The balance interfaces they described differed slightly and some were defined using sensors to detect bodily sway while others wanted to rely on the pressing down of either the toe or heel to accelerate or break. Having witnessed many different and good ideas we attempted to unify the designs into a single paper prototype, which is shown in Figure 7.7.

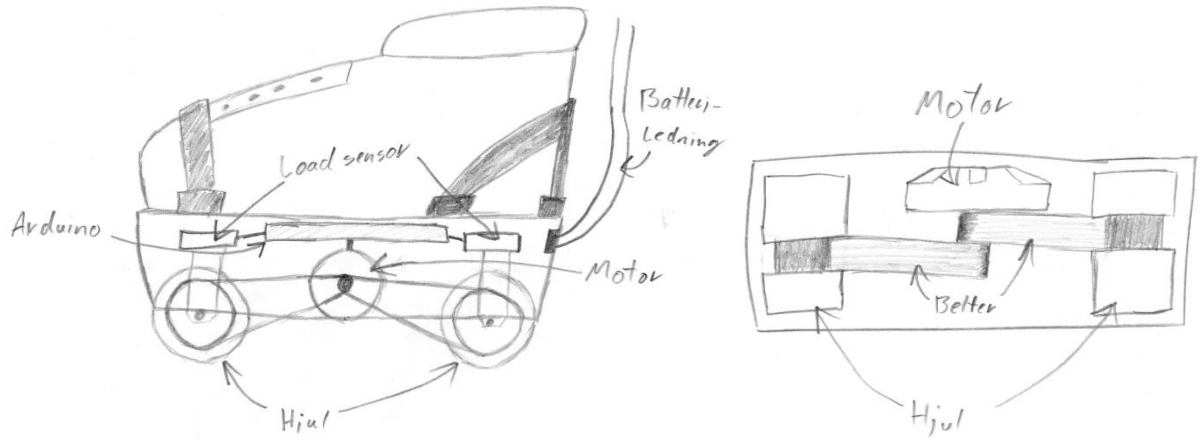

Figure 7.7 Paper prototype of the roller blades concept

This prototype was inspired by the external backpack battery idea, limiting size and weight of the base unit, and the detachable drivetrain idea that can be strapped to a normal pair of shoes. For each foot, we used a single motor that drives both wheels. The wheels are attached to load sensors that detect where pressure is applied. A battery cable, (and potentially also a communication wire going to the other foot-unit) runs up along the back of the heel.

After creating a paper prototype for each concept, we concluded that the skateboard concept was the most feasible to realize as a functional and testable prototype. The roller blades prototype, while certainly interesting, relied heavily on small parts and would likely require many strong custom made parts to ensure a reliable and safe user test. The skateboard concept also included several challenges such as building a sufficiently strong motor mount and connecting the motor to the wheels, but these were considered easier to overcome than with the roller blades concept.

With the concept decided, we completed an investigation of similar design solutions in order to learn more about what others are doing to perhaps enable an easier implementation stage. This investigation is found in Chapter 7.4. Once the investigation results had been collected, the prototype was revised in a secondary iteration, this time with a slight increase in fidelity. Now, what had been learned from the investigation of similar solutions was incorporated into the prototype where appropriate. Based on the things learned (See Table 7.1, p.79 for a summary), a more detailed second generation paper prototype was created, which is shown in Figure 7.8 and Figure 7.9.

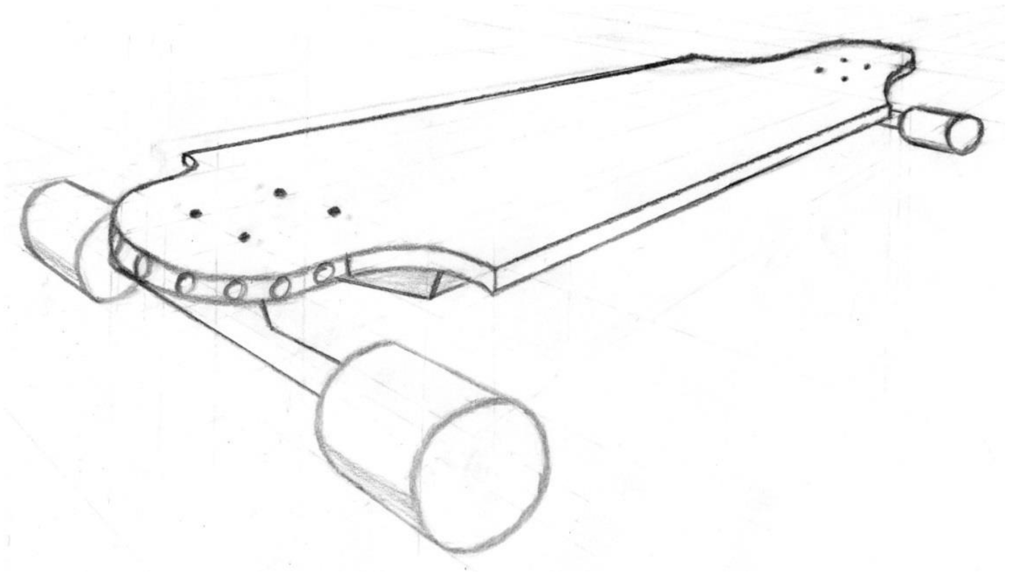

Figure 7.8 Second iteration paper prototype

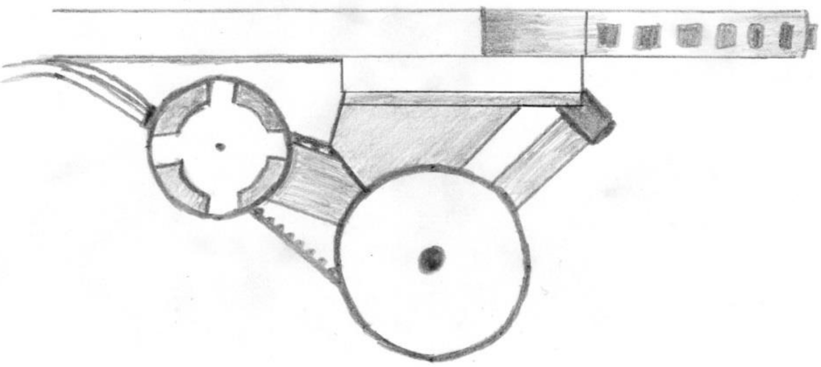

Figure 7.9 Second iteration paper prototype, belted drivetrain close-up

With the knowledge from the investigation of similar solutions, we had a better idea of what kind of motor and battery was needed, so we could more easily design a solution that could be implemented for testing purposes. We switched to a single motor

The low fidelity prototyping process revealed a set of potential obstacles in terms of building the functional prototype. The main obstacles were the following:

1. Implementing a mounted motor and transmission for acceleration
2. Implementing the two load sensors for detecting balance input
3. Adding the necessary electronics for converting the sensor input into a motor response
4. Adding a battery to power both the motor and the electronics

These obstacles and how they were solved will be described in detail in the implementation chapter (Chapter 8).

7.4 Investigating similar solutions

In this chapter, we present our results from a design evaluation of some of the more interesting similar products through researching electric skateboards online. Electronic skateboards are nothing new so this evaluation was useful for us to familiarize ourselves with current products in this segment before completing our paper prototype to see if something could be learned from these designs. The products we chose include: Boosted, LEIF, Marbel, ZBoard and OneWheel. The evaluation in full is included in Appendix B. Table 7.1 summarizes the results of the evaluation with the implications these have for our prototype.

7.4.1 Implications for the prototype

Table 7.1 summarizes the results of the evaluation and the implications this had for the prototype. These implications were used when refining the second iteration paper prototype.

Table 7.1. Results from the design investigation

Aspect	Investigation results	Prototype Implications
Interface	Most boards are controlled using a wireless remote, with the exception of Zboard and OneWheel which is controlled with body movements, but neither interface is the same as our approach.	There exists other products with related movement-based interfaces, but our approach seems unique[4].
Range	Range varies from around 10 - 40 km. The trade-off is largely related to problem of added weight.	Our requirements specify range sufficient for testing only, which should be feasible without adding too much weight.
Drive train	All back-wheel drive. Some have motors on both wheels, some only on one.	Single, back-wheel drive seems adequate and was chosen to minimize weight.
Motor and battery technology	Most use brushless DC motors for superior power-to-weight ratio. Either Li-Ion or Li-Po battery technology seems dominant.	Brushless DC motor was chosen for high power and low size and weight.

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[4] We were unable to find an electric skateboard with 4 wheels that is controlled using the riders' weight distribution.

Aspect	Investigation results	Prototype Implications
Other features	Some boards have head- and taillights as well as handles for easy carrying.	Lights were added to the prototype for added safety and interface feedback. The need for handles will be reevaluated at a later time.

7.5 Reflection on stage 2

In the second stage, a focus group was used to discuss and triangulate the needs discovered in the last stage, a design workshop that included a brainstorming and sketching session to generate design concepts, a design evaluation of current designs, and finally a low fidelity prototyping to create a design for the upcoming prototype implementation stage. Many HCI design methods have a focus on screen-based graphical user interfaces, such as card sorting and wireframes, and these are for natural reasons not particularly useful in this case. A method that could have been appropriate, however, was expert evaluation, which is a method were one or more experts will review a prototype and identify potential problems that users may face when using it (Maguire 2001, pp.616–617). This could be useful to identify problems and find solutions before the implementation stage. This expert could be a skater or a PMD domain expert. As mentioned in Chapter 6.4, we were unsuccessful when trying to get in contact with a PMD domain expert, and as a result, this was not a viable option. Getting in contact with a skater would certainly have been easier, but we ultimately decided to wait with this. An important aspect of the prototype was that the target group was not restricted to skaters, and including a person with long previous skating experience may skew the design more in favor of expert skaters, potentially steepening the learning curve for users without previous experience. In the end, it was decided that an expert skater evaluation may be useful, but only after the prototype is evaluated by the target group as a whole.

8 Stage 3: Implementation

Disclaimer: The following chapter documents the implementation of the prototyping process, and is outlined similar to a development diary with pictures, grouped into larger sections like transmission, load cells, drivetrain and software implementation. This chapter does at times get somewhat technical to make it possible for third parties to reproduce and validate the results. For those who just want to read a summary of the final prototypes, this is provided in Chapter 8.7, p.95.

Since the design idea selected during stage 2 was a skateboard form-factor, the natural starting point was to use a non-motorized skateboard as a base and modify it by adding the necessary components to implement the balance interface and drivetrain. I started with a standard longboard; a type of skateboard with larger wheels and a longer deck optimized for traveling rather than for performing tricks. This particular board was donated to me by a friend and can be seen in Figure 8.1.

Figure 8.1. A normal longboard used as the starting point for the prototype.

8.1 Approach

To build the prototype, electronics and the Arduino platform[5] was used to measure the riders balance position and translating this data into a throttle response that was sent to the motor. A single motor was mounted to the back trucks to drive one of the wheels. Balance was measured using two load cells, one for the front wheels and one for the back. Using the Arduino platform allows for rapid

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[5] Arduino is an open-source physical computing platform that makes it easy to work with electronics through a microcontroller. See www.arduino.cc for more info.

prototyping using different circuits and code implementations to get an optimal interface. The load cells controls acceleration and breaking only, as longboards inherently turn using balance when the rider shifts his/her weight from side to side. This causes the board to tilt as both trucks turns inwards, thus turning in the direction where force is applied. For the drivetrain a brushless outrunner DC motor was connected to the wheel using a timing pulley and belt, and both the motor and other electronics was powered by a Lithium-Polymer battery.

8.2 Wheels, transmission & motor mount

According to the design specification, the size of the wheels needed to be large enough to easily ride over smaller rocks, dropped curbs at pedestrian crossings, and other smaller urban obstacles. The wheels on the board were 65mm in diameter, which could possibly be too small for some of these obstacles. A larger set of wheels could also make it easier to create the transmission, as it would be possible to attach a wider range of timing pulley sizes to the wheel. For this reason the wheels were upgraded to a set of 85mm diameter wheels (Figure 8.2).

Figure 8.2 The 85mm wheels used on the prototype

Without access to professional tools, mounting a timing pulley to one of the wheels seemed almost impossible at first. With a backup plan of acquiring a custom made timing pulley, it was decided to first try to simply glue a timing pulley to the wheel using Sugru moldable glue[6]. The main challenge with this approach was to perfectly center the timing pulley on the wheel. To make this easier the wheel was flipped around and placed it on top of a vertically standing truck, and then a ring of Sugru was attached to the wheel for mounting the pulley (see Figure 8.3).

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[6] Sugru is a moldable silicone glue that bonds to most materials and turns into hard rubber after being exposed to air for 12-24 hours. See https://sugru.com/ for more info.

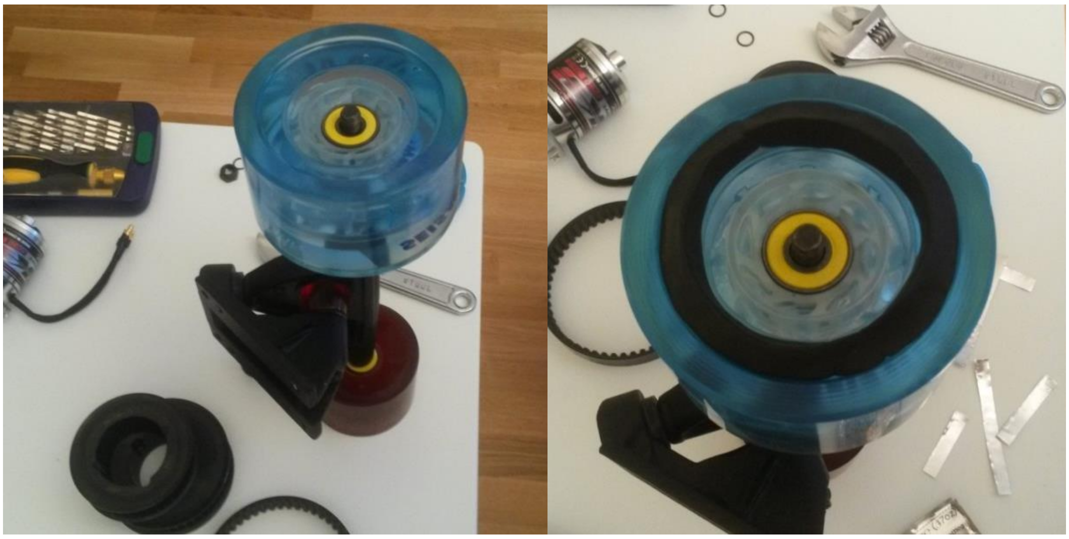

Figure 8.3 The wheel on vertically standing truck (left). Close-up of the wheel after attaching Sugru (right).

With the ring of Sugru on the wheel, the pulley was pushed against it. The wheel could then be spun on the vertical trucks to spot misalignments more easily as the pulley wobbled and the necessary adjustments was made to make it perfectly centered on the wheel. Once the pulley was centered the Sugru was left to cure overnight into a hard adhesive rubber. The final wheel with the pulley attached to it can be seen in Figure 8.4. This approach ended up working reasonably well and the bonding was surprisingly strong and has yet to fail even after many months of heavy usage. While this is hardly a permanent solution, it worked great for the purpose of the prototype as a cheaper alternative to acquiring custom-made parts. Still, it should be emphasized that I do not recommend this approach to anyone looking for a permanent pulley attachment and I expect the bonding to fail at some point.

For the motor mount Actobotics aluminum parts was used to build the mount itself, and again Sugru was used as a low-cost boding method for attaching the mount to the back truck. The mount went through several iterations to ensure a strong mount, as most of the components used consisted of fairly thin aluminum plates, and for this same reason the mount was attached to both sides of the trucks (see Figure 8.4, on the right).

Figure 8.4 Timing pulley attached to wheel (left, middle), and first iteration motor mount (right)

When attaching the mount to the trucks, Sugru was placed between the Actobotics clamp and the truck hanger (see Figure 8.5). This was sufficiently strong for the sake of testing the prototype and as a side effect the cured rubber actually seemed to absorb much of the shocks and vibrations while riding. The transmission was then completed with a small pulley attached to the motor shaft and a timing belt to deliver power to the wheel. The timing pulleys and belt used was the HTD style timing pulley with 5 mm pitch and 15mm width. The motor shaft had a 12-teeth pulley attached to it and the wheel had a 36-teeth pulley. The reasons for choosing these pulley sizes will be explained later in relation to the drivetrain setup (page 88) as these choices are highly dependent on the motor characteristics.

Figure 8.5 Clamp filled with Sugru before attaching (left), and trucks with both clamps attached (right)

8.3 Load cell implementation

Getting the load cells to work reliably was actually the most challenging aspect of building the prototype. Testing of the cells started before the design of the prototype was established as weight was considered to be the most likely method for measuring balance regardless of design. With only a basic understanding of creating electrical circuits, getting a usable reading from the cells was not a straight-forward process. When load is applied to a load cell, its resistance changes a tiny amount, which translates into a change in voltage too small to be measured with an Arduino. Because of this, the signal must be amplified, typically with an instrumentation amplifier (InAmp). To get the load cells, a standard bathroom scale was disassembled and the 4 sensors found inside removed. This scale used a set of 3-wire load sensors able to measure up to 50 kg, which, just like a strain gauge, is half a Wheatstone bridge[7]. To complete the bridge, a secondary passive load sensor (or resistors of equal resistance to the sensor) must also be connected to amplify the difference between the signals. Feeding both signals into the InAmp, configured to amplify the signal 6 000 times, provided an output of roughly 5 volts, readable by the Arduino. Testing of this setup can be seen in Figure 8.6.

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[7] For more info on Wheatstone bridges, see http://www.electronics-tutorials.ws/blog/wheatstone-bridge.html

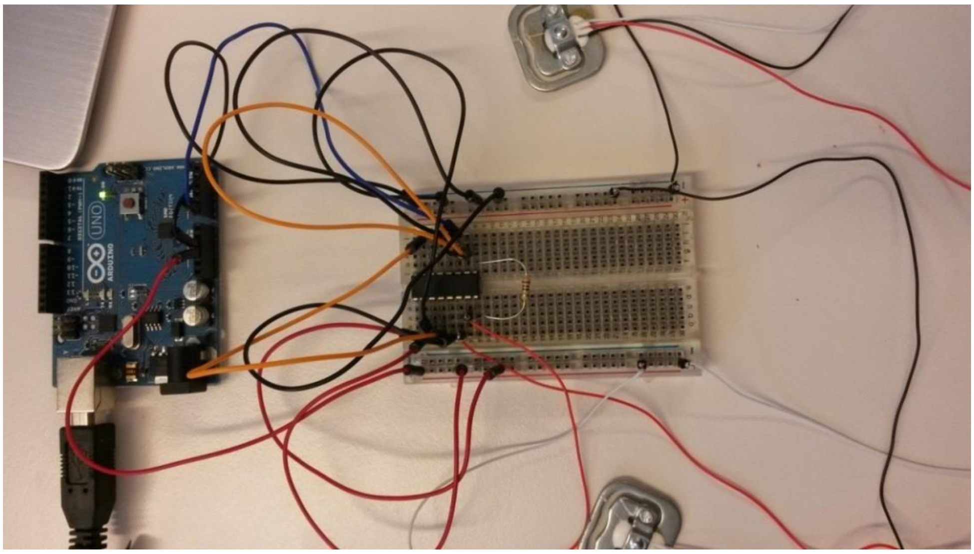

Figure 8.6 Testing load sensors using an Arduino UNO and a 16-pin instrumentation amplifier

To get a usable reading while shifting balance on the board, a hole was cut in the risers between the trucks and the board to fit the sensors inside them (see Figure 8.7). By allowing the flexing part of the sensor to poke out of the risers, weight would be applied directly on the sensor to measure the applied force as long as the screws holding the trucks to the board were not fully tightened.

Figure 8.7 Risers on the board before cutting (left), and after cutting riser to fit the load sensor inside (right)

Getting a consistent reading proved to be a challenge as the thin wires on the sensors would occasionally break and using different sensors as the passive sensor would also vary the output range. The sensors were soldered to a printable circuit board (PCB) in hopes of remedying this issue (see Figure 8.8), however this only partially solved our problems and the sensors gave slightly different output ranges each time they were tested.

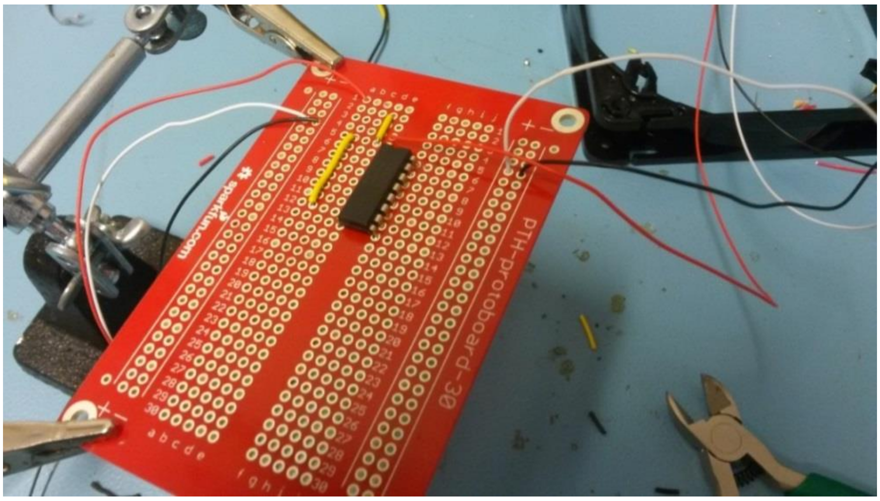

Figure 8.8 Soldering load sensors to a bare PCB

8.3.1 Second iteration load cell

Because a reliable load cell was essential to the prototype, the 3-wire load sensors we replaced with 4-wire load cells that consisted of a full Wheatstone bridge in a single unit. To minimize issues with the wires, Connectors were soldered to the cells and we made thicker extension cables that would connect the PCB to the cell (see Figure 8.9).

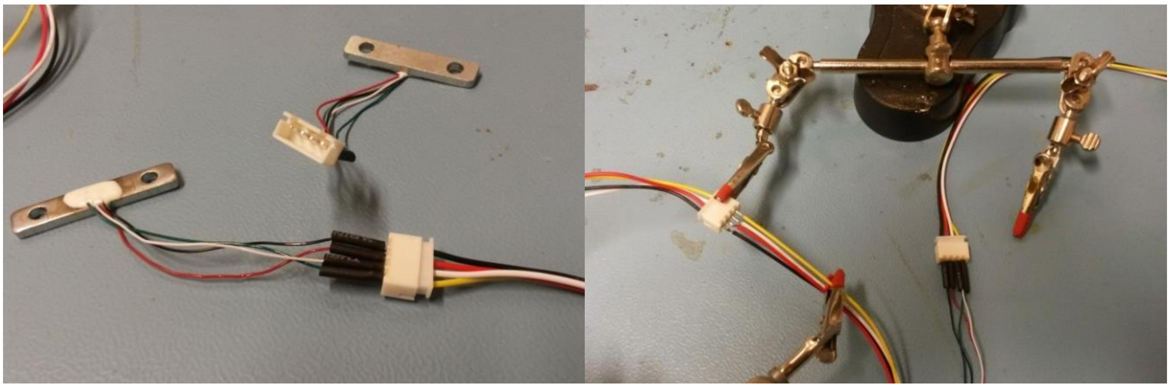

Figure 8.9 New load cell with soldered connector (left) and extension cables for the load cells (right)

The initial approach with these new cells was to create a small bump under the deck of the board that the cell would press against when weight was applied. Figure 8.10 shows this setup using screw washers as the bump on the board. However, this approach gave highly inconsistent weight readings when turning the board. In fact, this was also a problem with the previous sensors used, but not as noticeable due to the readings being inconsistent overall.

Figure 8.10 Close-up of bump and load cell before installation (left). Installed sensor inside the truck riser (right)

To prevent the cell from detecting turning forces, the trucks had to be secured to the board in such a way that they would not wobble due to the untightened screws. This meant that one screw on the left and right side of the trucks had to be securely tightened to enable the load cells to detect only the forces that come from leaning forwards or backwards on the board, as opposed to from side to side. This would require a different setup for the load cell to detect weight. The load cell was turned 90 degrees to align it with the length of the board and it was suspended on top of a sideways U-shape that would rest between the deck and trucks. On one side (closest to the edge of the board) the load cell was then free to flex as the trucks pressed against the suspended cell when measuring weight. The screws were therefore only fully tightened on the opposing side to prevent the trucks from wobbling sideways. This configuration can be seen in Figure 8.11. Notice that the truck has a small indented flat area in the center between the screw holes. This flat area is pressing against the suspended side of the load cell when weight is applied.

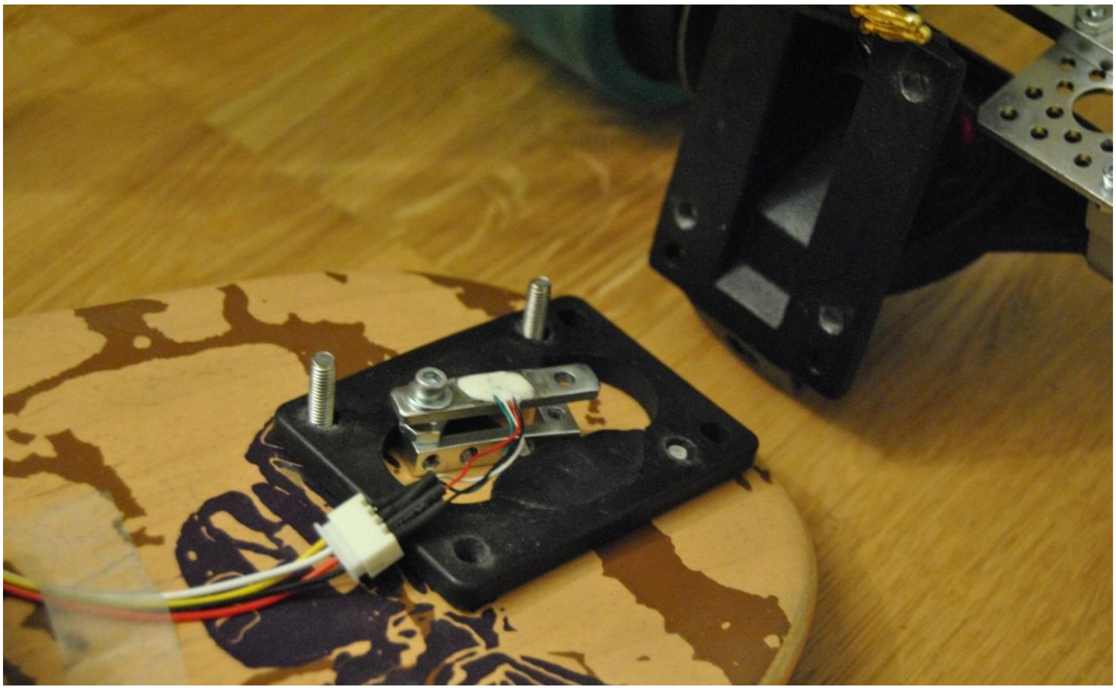

Figure 8.11 Final load cell configuration with truck removed

This approach worked perfectly and gave very precise readings from the cells as weight was applied and could detect small leaning movements to the front and back sensors. Tilting the board while turning hardly affected the output at all and both sensors could detect leaning movements fairly accurately while turning.

8.4 Drivetrain and battery setup

For the battery and motor setup, we used components intended for Remote controlled (RC) hobby equipment such model airplanes and cars. The brushless DC motors used in these devices are very powerful for their size. The LiPo batteries are able to deliver high voltage and amperage in a small and light package at a fairly cheap cost making them ideal for this application. Since there isn’t much room under a skateboard, there are limited options for gearing down the motor to a more usable road speed. Because of this, one of the main problems when it comes to finding the right motor is to get a motor that is slow enough while still delivering the required torque. Due to cost concerns and the fact that we didn’t need a high top speed at all, we acquired a battery of 14.4 volts. Ideally you would want considerably higher voltage than this, but for the sake of this prototype it was ok for testing purposes. The relationship between volt, current, motor revolutions per minute (RPM), gearing, resistance and efficiency is a whole topic even of itself so we will try to be brief.

The motor we selected for the first iteration had an output power of approximately 1000 Watts and 350 RPM per supplied volt, resulting in a maximum RPM of 5040 when applying the full 14.4 volts. Using the formula for calculating linear velocity from RPM (see Formula 8.1) we know that, without any gearing, the theoretical top speed with this setup is 80 km/h without load. This would certainly be geared way to high and would not provide even nearly enough torque. We therefore wanted to gear the motor down as much as possible by attaching a small pulley to the motor and a large pulley to the wheel.

$$v = \frac{\emptyset\pi \times RPM \times 60}{1000}$$

Formula 8.1 RPM to linear velocity in km/h

With a HTD belt with 5 mm pitch, the smallest available pulley on the motor was a 12 teeth pulley with 19.1 mm pitch diameter. The skateboard wheels being 85 mm in diameter the largest we considered safe would be a 36 teeth pulley of 57.3 mm pitch diameter. With the 60 mm diameter flanges this gave us 12.5 mm clearance to the ground. Larger than this seemed like it could potentially cause problems. This setup gave us a gear reduction of 1:3 so for every full wheel revolution the motor makes three revolutions[8]. Our maximum RPM to the wheel would then be reduced to 5040 / 3 = 1680 RPM. Using Formula 8.1 again we calculate a top speed of approximately 27 km/h without load. Although even more reduction would be preferred for increased torque, this was much better and seemed adequate for an initial test on a flat surface. A visual illustration of the gear reduction transmission can be seen in Figure 8.12, while Figure 8.13 shows a picture of the full setup with the first iteration motor with the belt and pulley transmission to drive the wheel.

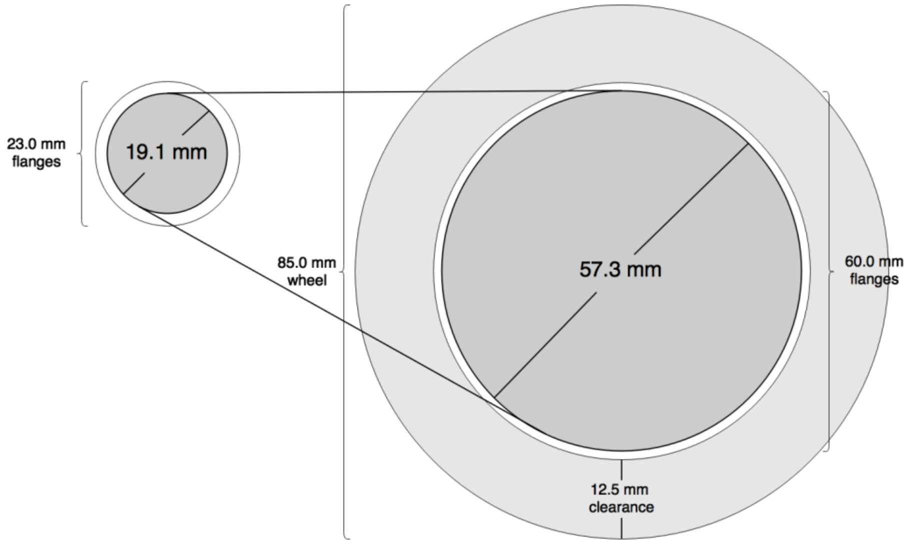

Figure 8.12 Transmission setup with small and large timing pulley

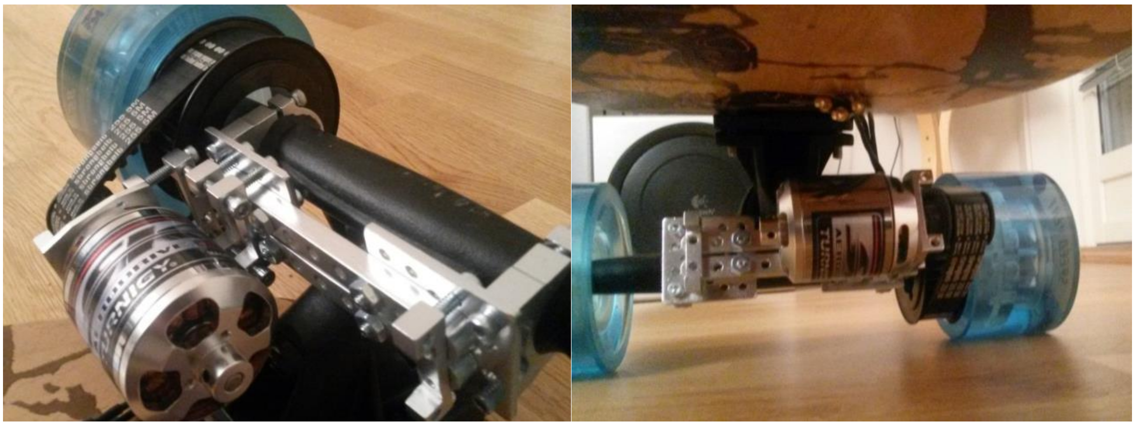

Figure 8.13 First iteration motor mount and transmission

To control a brushless motor requires an electronic speed controller (ESC). The electronics that goes into an ESC are fairly complex, so instead of building one from scratch we used an ESC intended for RC cars with braking and reverse support. These ESCs can be controlled with a simple servo signal from the Arduino to drive the motor in either direction. The ESC was powered by a Li-Po battery with

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[8] Large pulley diameter divided by small pulley diameter: 57.3 / 19.1 = 3.

4-cells, 14.4 volts and 6 Ah. The ESC could then power both the motor as well as the Arduino using a 5-volt Battery Eliminator Circuit (BEC) integrated into the ESC. We tested this setup before the balance interface was implemented using a simple potentiometer connected to the Arduino that converted the signal from the variable resistor in the potentiometer into a servo signal that was sent to the ESC (see Figure 8.14).

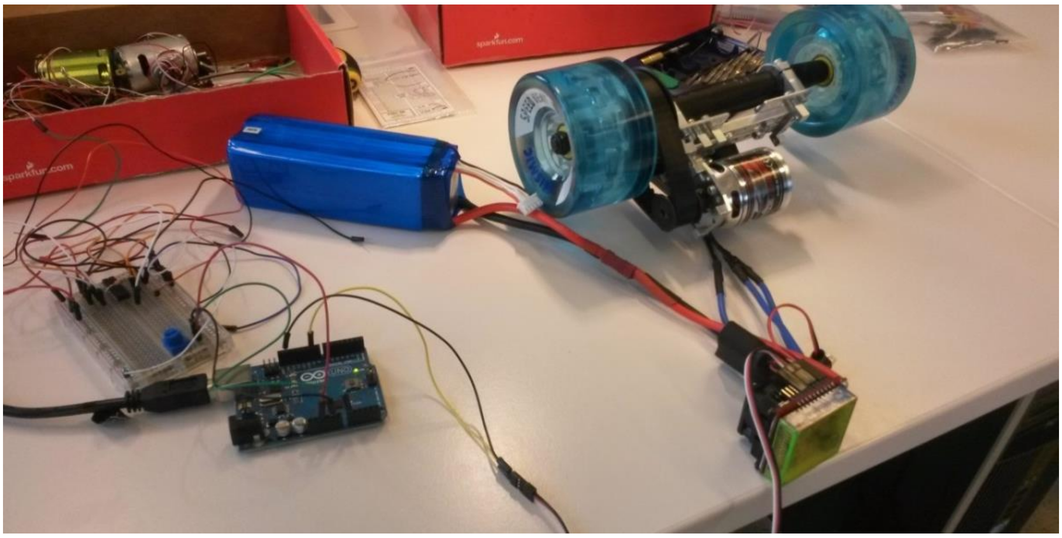

Figure 8.14 Testing the brushless motor driving the wheel with a RC car ESC

We now had all the necessary components to complete our first iteration prototype which can be seen in Figure 8.15. At this point we simply taped the components to the underside of the deck as we did not want to create a casing for the prototype until we were sure of the final dimensions of the battery that we would end up using for the later iterations. This version of the prototype was used in our first usability test with a balance simulation as the balance interface was not reliable at this time.

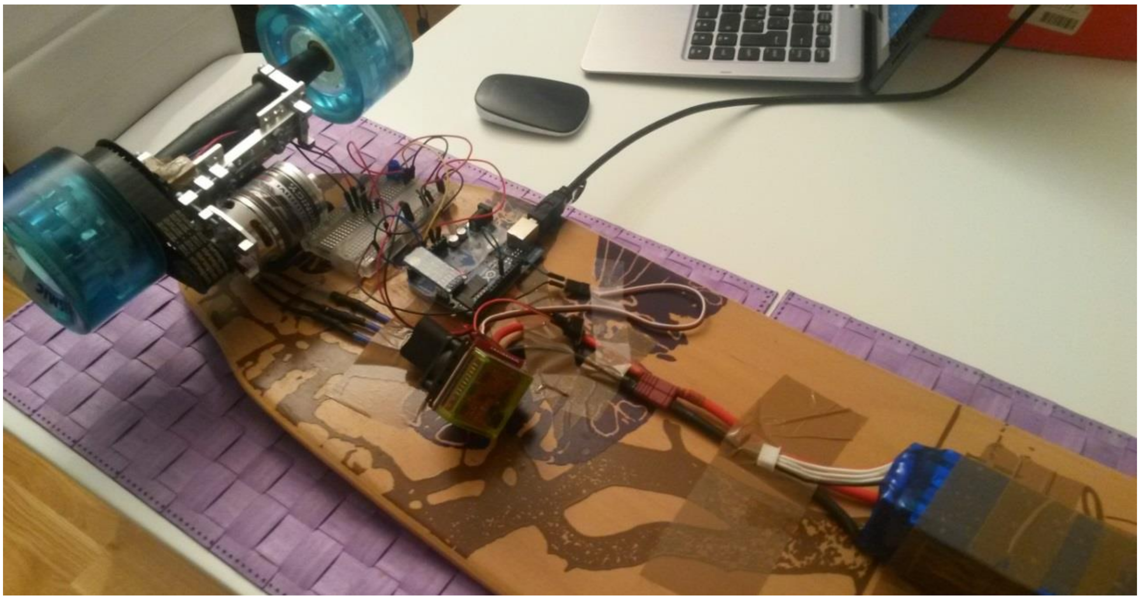

Figure 8.15 The complete first iteration prototype

8.4.1 Second iteration drivetrain

The main problem with the first iteration drivetrain was low torque and poor start-up acceleration. To improve this, a larger and more powerful motor of 2600 watts and 270 RPM per volt was acquired to give the board better low speed performance. A slightly more powerful ESC was also used, and a larger battery in a slimmer package for increased ground clearance. The ESC and battery setup was kept at 14.4 volts to minimize costs. The new motor had a different mounting setup so this required a modified motor mount. The new mount was slightly more rigid so this ended up as an overall improvement of the whole drivetrain. The second iteration drivetrain with a new motor and cleaner motor mount design can be seen in Figure 8.16. Notice also the new battery and that the electronics have been soldered the PCB.

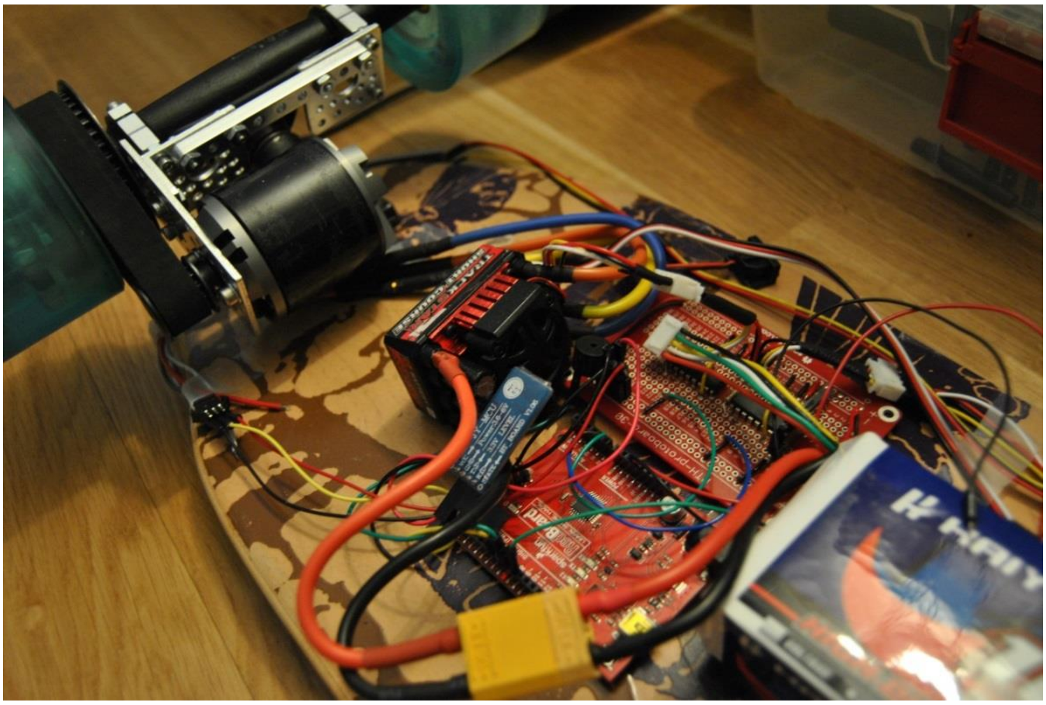

Figure 8.16 The second iteration drivetrain setup with more powerful electronics

8.5 Software

The Arduino microcontroller was not only used to read load sensor values and sending a signal to an ESC, but also other features of the prototype, including safety features like LED head lights and tail lights and Bluetooth support for mobile App support. The architecture layout of the Arduino software is shown in Figure 8.17. The code is released as open source and is available at https://github.com/aleksre/Powerboard. The Bluetooth and mobile app implementation was done as a group project in parallel with the rest of the prototype implementation in relation to a university course on mobile systems. The purpose was both to create an app that could be used to get additional information on the state of the prototype, such as battery capacity or distance traveled, make configuration changes such as limiting top speed or turning lights on or off, troubleshooting without a computer, and various other features. This side project had its own separate development process, which is documented in the report available at https://github.com/aleksre/Powerboard/raw/master/Other/App-report.pdf [Only in Norwegian]. The storage controller was also added to the Arduino code so configuration changes made was kept when the prototype was turned off. The LED lights and sound implantation would, in addition to being a safety measure, provide the rider with additional feedback on their body movements. A LED strip was mounted at the front and back with headlights and taillights while riding and these would expand and contract the number of lit LEDs as weight was distributed to the board. The sound controller was a simple piezo speaker that made square wave sounds when activating or deactivating driving mode, so that a user would be given feedback without having to look down at the board when activating, or if sunlight made the LEDs hard to see. The load cell controller made continuous measurements of the two load cells and smoothed out the data to avoid unwanted sudden spikes in measurements.

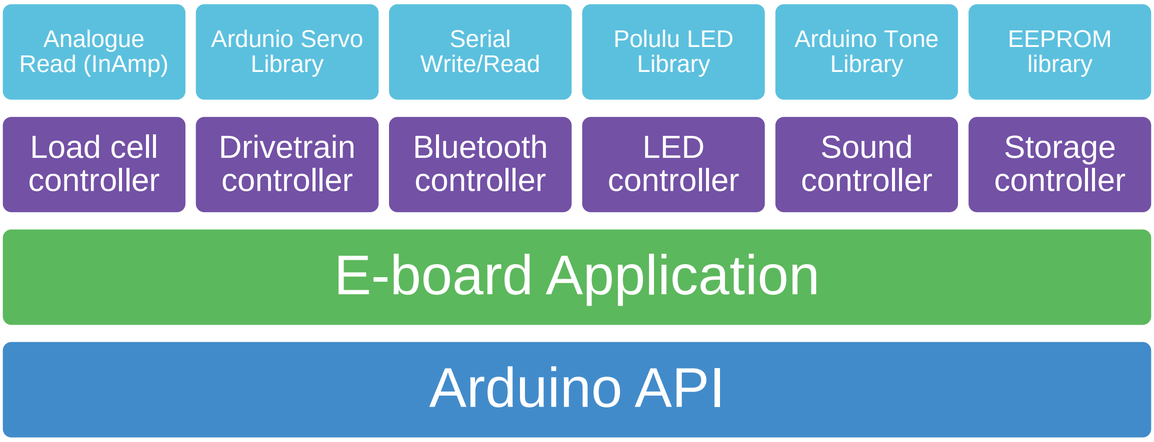

Figure 8.17 Architecture layout of the code running on the Arduino microcontroller

8.5.1 Activation and control system

Since the board is controlled by detecting the distribution of weight on the board, a problem quickly arises: How do you prevent the prototype from driving off as you are getting on? This question is just one of many potential problems identified throughout the study. Since this is presumably the first interface of its kind, these questions have never been previously answered and solving them in user friendly ways, without handheld or manual controllers requires additional technological innovations.

This problem in particular was solved by having the prototype automatically detect when a rider is safely standing on the prototype with both feet. When the prototype is first turned on, it will be in a *standby* mode and the drivetrain will be off regardless of weight applied. To activate *driving* mode, both load cells must detect roughly equal weight for a short period of time. In other words, activation of the drivetrain happens only after both feet are on the board and the rider is standing normally. This ensures that the rider can get on while the prototype is standing still without fear of it suddenly accelerating. Similarly, when no weight is applied, the board deactivates driving mode automatically and stops the motor.

It was quickly discovered that standing normally on the board would not always result in equal weight applied to the front and back load cells. This was highly dependent on not only feet placement but also the individual and subjective preference in how the rider stands on the board. Because of this, it was decided to have a fairly wide activation range of 30%, and automatically calibrate the center, or *balanced,* position to the rider's weight distribution when activating driving mode. This calibration process would then set this position as its new *'centered'* position and scale the acceleration curves according to this position. A linear acceleration curve was first used, but this made it difficult to hold a steady slow speed. Additionally, it was almost impossible to reach top speed due to the fact that this required that all weight was applied to one of the load cells. After some experimentation with various acceleration curves, it was decided to use an exponential curve that had a 10% wide *'balanced'* deadband and that reached full speed at 85% forwards or backwards lean. This exponential curve means that a wider range of postures can be used for fine-tuning slow speeds, since the added precision is especially important at slower speeds, such as when trying to match walking speed. Figure 8.18 shows a visual illustration of the resulting exponential acceleration curve used in the Arduino code, with the 10% deadband (in green) and 30% activation zone (in turquoise). In addition to this, acceleration ramping was implemented, in response to the observation that the acceleration was too sudden if the rider leaned too much forwards initially. This meant that even if the rider leaned hard forward right away, the acceleration rate would steadily accelerate to that speed over several seconds.

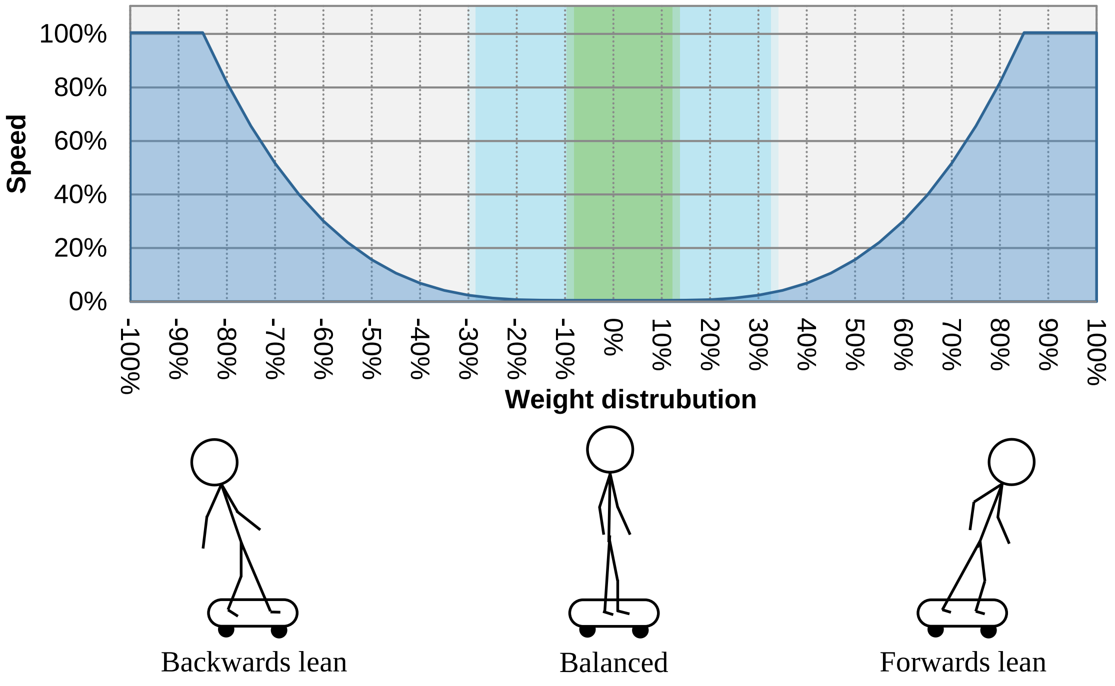

Figure 8.18 Illustration showing the acceleration curve based on the riders posture

8.6 Finalizing the prototype

At this point, all the electronics had simply been taped to the underside of the deck, which did not look very nice. This was also brought up as a negative point by several participants in formative test, which we will return to in Chapter 9.1. To protect the electronics, and make the prototype look a little more professional, a plastic enclosure was created from the lid of a cheap plastic storage box. The lid was cut in several pieces and mounted to the deck to enclose the electronics. The lid was created to be easy to open or close with Velcro straps, and all the tape mounting the electronics to the deck was also exchanged with Velcro straps glued to the deck and components with rubber bands holding the battery in place, so that all individual electronic parts could also be easily removed or replaced. Additionally, a new power switch to turn the prototype on or off was soldered to the ESC which would allow for mounting to the enclosure to prevent having to open the lid to turn it on or off.

Figure 8.19 Cutting a plastic casing for the prototype electronics

The end result was a prototype that visually looked close to production-ready with a full enclosure, a power switch on the side, headlights and taillights, and a motor mounted on the back wheel. Of course, in reality, this was still a fairly fragile construction, but good enough for a user test. The final prototype in its second iteration can be seen in Figure 8.20.

Figure 8.20 The final version of prototype #1

8.6.1 Prototype #2

Once the second iteration prototype was complete, it was decided to create another prototype for the test. Multiple spare parts had been acquired during the creation of the first prototype and with another Arduino, battery and motor controller already available, there was little work required to create a second prototype. With two prototypes for the test, each participant could get twice as must testing time, and it would likely lower the threshold for participation since multiple people could perform the test simultaneously. Prototype #2 had a similar setup, but had a slightly longer deck and non-essential components, such as Bluetooth and LED lights, was not implemented.

8.7 Prototype implementation summary

Table 8.1 presents a summary of the resulting two electric skateboard prototypes built and used during testing. Additionally, Table 8.2 shows a feature overview of the main differences between prototype #1 (in both of its two iterations) and prototype #2.

Table 8.1 Summary of the completed prototypes

Aspect	Summary
Setup	• Standard longboard with back-wheel drive using a single electric brushless motor. • Battery pack and other electronics mounted to the underside of the skateboard deck. • Electronics controlled using the Arduino microcontroller.
Interface	• Lean forward to drive, lean back to brake or go in reverse. • Turning works like any other skateboard (leaning left or right). • Input from two load sensors located between the deck and the wheels are converted to a motor response by the microcontroller.
Activation / Calibration	• Prototype will not move while rider is getting on (prototype is in *‘standby’*) • Only once equal weight is applied to the front and back of the board, it will calibrate to the persons weight and activate *‘driving mode’*. • Board turns off the motor and returns to *‘standby’* automatically when no weight is applied.

Aspect	Summary
Input / Output	• In *'driving mode'*, the microcontroller calculates and sets the motor speed based on the riders' weight distribution. • Input smoothing and ramping is implemented to prevent the board from accelerating too quickly due to sudden movements. • In *'standby'*, the motor is off and LED lights provide feedback on the riders' weight distribution to tell them how the board is interpreting their movements.
Other	• Mobile app for configuration and the possibility to override the balance interface with a manual slider-controller. • Headlights and taillights give the rider feedback on their weight distribution. • Activation and deactivation notification sound feedback help the rider know when the board changes its status.

Table 8.2 Main differences between the prototype iterations

Feature	Prototype #1		Prototype #2
	1st iteration	2nd iteration	
Electric motor power	1000 W	2600 W	2000 W
Battery pack capacity (14,4 volts)	6 Ah	10 Ah	10 Ah
Balance user interface	-	Yes	Yes
Controllable using mobile app	Yes	Yes	-
Audio feedback	-	Yes	Yes
LED lights feedback	-	Yes	-

9 Stage 4: Evaluation

This chapter includes results that are relevant to the research question. These are from both of the usability tests from stage 4. The first is a formative test with a balance simulation, and the second is a summative test with a functional balance interface. More information about the formative test and the implications this had for the rest of the study can be found in our paper *'Implications for Design of Personal Mobility Devices with Balance-Based Natural User Interfaces'* (Rem & Joshi 2015), available in Appendix F.

9.1 Formative test: Balance simulation

Fourteen participants completed the first, formative usability test with a balance simulation. In spite of several technical difficulties with the prototype during testing, virtually everyone who tried expressed how much fun it was to ride. The participants had mixed previous experience with skateboards and longboards (see Table 9.1), and those with little experience in particular had difficulties with keeping their balance and turning during their first few seconds on the board. However, they learned quickly and after only short while you could see a noticeable difference, which was visible as they kept a straighter, more confident posture, showed improved turning ability and willingly increased the driving speed. Several of the participants wanted to ride the board back to the starting point after completing the test. Many of the participants also kept riding for longer than necessary, and some also came back for more after a few minutes because they wanted to try it again. Table 9.1 lists a set of ratings from observations and the survey. Even with our homogenous group of people, previous skating experience varied greatly (SD=1,94) and spanned the entire range from 1 (very low) to 7 (very high). In spite of this, the overall prototype satisfaction was high (6,14 out of 7), with a standard deviation of just 0,84.

Table 9.1 Ratings of various attributes from the user test

Rating from 1 (very low) to 7 (very high)	Mean	SD
Previous skateboard/longboard experience	3,29	1,94
Overall prototype satisfaction	6,14	0,84
Observed amount of leaning forwards and backwards	1,71	0,73
Observed ability to turn left and right	4,57	1,87

During the simulation, the participants were asked to lean forwards on the board to accelerate as if it was their body weight distribution that controlled the speed of the board. The amount of visible lean did not vary substantially between the participants (see Table 9.1). Some participants hardly showed any visible lean at all, and others leaned only a little bit. The amount of lean on toes and heels (to turn the board) varied slightly more, but could be related to the participants' previous board experience. Those with more experience leaned from side to side more visibly than those with less experience.

Figure 9.1 Participants standing on the prototype board

Next, the participants were asked how they would prefer the device to tilt elastically as they shifted their balance, between the choices: side-to-side (turning), front-to-back (accelerating/breaking), both or neither. 78,6% of the participants said they wanted side-to-side tilt only, i.e. elastic when turning and isometric when accelerating and breaking, similar to a traditional longboard. Further, we asked how much weight should be applied on the front of the board before the vehicle starts accelerating. All participants gave values in a range between 60% and 80% of body weight (mean=67,59 SD=7,76). Finally, the participants were asked for suggestions on improvements and other comments, and the vast majority of participants gave suggestions related to various technical issues, mostly motor stuttering at slow speeds due to the use of an underpowered motor in the prototype. Other comments were primarily about how fun it was, and two participants in particular called for balance as input rather than a simulation. One participant wanted more clearly marked areas for where to place your feet, and one participant expressed a concern for destroying the fragile looking prototype during testing because of the unprotected electronics below the deck.

Figure 9.2 Participants riding the prototype board during usability test

9.2 Summative test: Functional prototype

The final usability test using two fully functional prototypes provided us with largely positive results on how the balance interface itself is experienced, as well as how the prototype overall is experienced. The results came from multiple sources: A paper survey following the test with a mix of qualitative open-ended questions and quantitative Likert-scale questions, qualitative observations, and the informal qualitative conversations we had with the participants. Because the topic of interest was on how the balance interface was experienced, more emphasis was given on what they said, rather than on what they did. Thus, observations were mostly used to determine the extent of which the participants had a successful interaction, and to identify usability problems and limitations with the prototype itself.

Figure 9.3. Both prototypes being tested by participants

9.2.1 Conversations with the participants

Through our talks with the participants the feedback was positive and they enjoyed riding the prototype, even with some technical issues like stuttering acceleration from a full stop and brakes that were a little too hard and sudden when initiated. One participant said *"This is awesome!"*, while a participant that arrived with his own longboard said *"Well, now I'm jealous"* when he saw participants testing the prototype. The participants generally agreed that balance worked great as an input modality, and when asked what could be improved they would almost universally list one of the known technical limitations, mainly poor startup acceleration and braking performance. Through our conversations the discussion quickly shifted towards them asking about the implementation such as what kind of motor was used, if the prototype was running Arduino, or about the specifications such as top-speed or battery capacity.

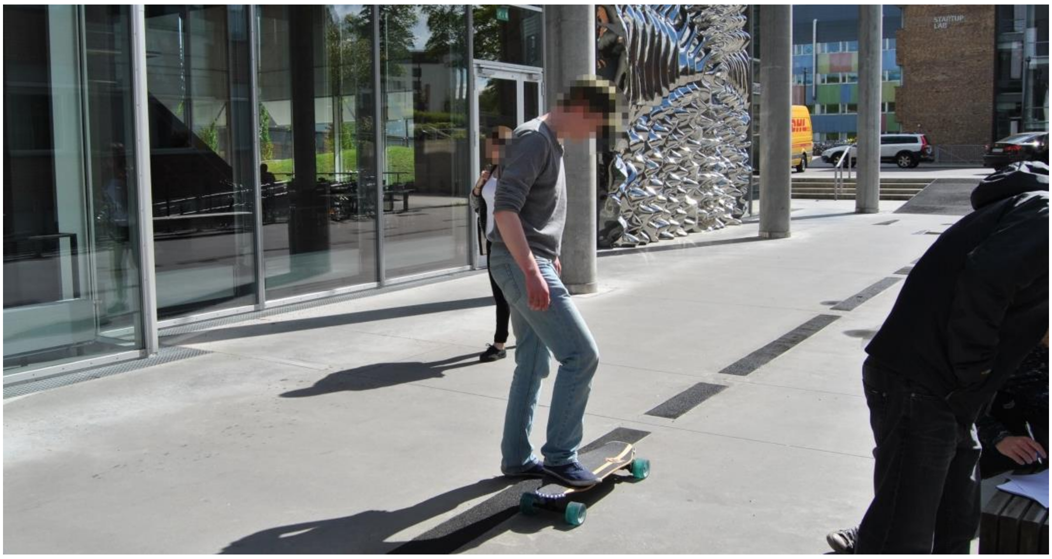

Figure 9.4. One of the participants are getting on prototype #1

Some participants expressed that they had trouble reaching high speeds, while others seemed to have no trouble. The reason for this was likely a side effect of the motor speed ramping described in Chapter 8.5. If the rider accelerated to a certain speed, then balanced the board, and later leaned forward to accelerate again, the ramping would reset and the prototype would need several seconds to accelerate further. This was because only the motor controller, and not the Arduino software, was aware of the actual speed the motor was running at, so in the Arduino software it had to be assumed that acceleration must be ramped up slowly every time weight is shifted from a balanced position to a leaning position. The side effect of the ramping caused a mismatch between the participant's conceptual model where leaning forward would always result in acceleration, and what the device actually did. This was therefore valuable feedback on something that should be changed in later iterations of the prototype.

Figure 9.5. Both prototypes being tested by participants

About halfway through the test, one of the load cells on prototype 2 stopped working. This made it impossible to interact with the prototype using balance. Rather than to cease testing with prototype 2 altogether we decided to let people try controlling it using the mobile app similar to our previous usability test. This gave the participants an opportunity to compare the balance interface to an electric skateboard with a handheld controller. At this point we also made sure that no participant tried prototype 2 only, and instead used it as a way to compare what riding an electric skateboard would feel like without the balance input. The participants had mixed opinions regarding the mobile app controller. Most participants said using balance felt more natural and more fun overall. One participant in particular expressed that the added precision offered by the handheld controller made it easier to ride and control the speed more accurately to his needs: *"I think I like the app control a little better. I find it easier to reach higher speeds with it"*. Another participant did not like the app at all: *"Balance is much easier. When I use the app I focus all my concentration on controlling the speed and I find myself looking at the screen constantly to make sure I have it where I want it."* In other words, when the balance interface was used she could pay more attention to her surroundings and focus on the experience of riding, but with the app it seemed to have demanded much more cognitive load and the extra attention needed made the experience less enjoyable. From a safety perspective, a lower attention demand from the rider is certainly a good thing when dealing with a powered vehicle. After all, even when using a handheld controller, you still have to shift your balance as you are accelerating and breaking to prevent yourself from falling.

Figure 9.6. A participant is carefully accelerating using balance

9.2.2 Observations

Many of the participants without skateboarding experience, when first stepping on the board, had trouble maintaining their balance intentionally and would wobble from side to side while seemingly having trouble with turning intentionally. They were largely unable to achieve controlled movements and much effort went into restoring their balance as they wobbled. When asked if they thought the board was too unstable or tilted too easily, they for the most part disagreed and excused their low stability with the fact that they did not have prior skateboarding experience. After a few minutes once the participants started getting familiar with the tilting of the prototype the situation started to improve.

This improved skill level was not exclusive to turning, but also manifested itself in other aspects of controlling the prototype. Some participants seemingly did not trust that the prototype would help them remain balanced, and refrained from accelerating beyond walking speed for the first minute or so. However, almost all participants showed a clear and visible improvement in skill level even after only a couple of minutes of testing. A few participants in particular seemed to get very confident and would glide past the testing area with ease while turning in smooth curves, with no trouble keeping a desired speed, accelerating, braking or turning at will. The area of the prototype interface that the most participants struggled with was clearly turning. Braking also caused some issues but participants expressed that this was because of the abruptness of it rather than an issue with the concept of leaning back, which they agreed with. Acceleration (in both directions) did not pose much of an issue, and getting on or off, as well as activating driving mode seemed also to work well for most participants.

Figure 9.7. Prototype #1 being tested

9.2.3 Paper survey responses

Qualitative questions

As mentioned the paper survey handouts that were filled out after test completion combined qualitative open ended questions as well as quantitative Likert-scale questions. We will first present the qualitative questions, which were intentionally worded to be quite unspecific to enable each participant to choose for themselves what to comment on. The survey included four questions:

1. What was your overall experience of the prototype?
2. What did you like best?
3. What should have been different?
4. If you experienced any technical issues, please state them here.

Overall prototype experience

In response to our first question on the overall impression of the prototype, the responses were almost universally positive. Many participants focused on the enjoyment of riding:

- *“A lot of fun* - *much better than a regular skateboard that you have no control over”*
- *“Incredibly fun and surprisingly easy”*
- *“A lot of fun, could have played more with it. I liked the mobile app for the board”*
- *“So much fun! It was a little hard to drive since I have zero experience with skateboards and balance, but it was a lot of fun”*

Many participants also expressed that they were impressed with the concept itself:

- *“Fun concept, nice execution with the lights”*

- *"Very good with lots of potential"*
- *"Impressive for just a prototype"*

Some also specifically commented on their learning curve:

- *"Really good, it was a ton of fun to drive and it got a lot more fun along the way"*
- *"It was a lot of fun to test both skateboards, they worked well, just had to get used to it"*
- *"A little slow at first, but ok control once you find your balance"*

Some also provided more practical feedback on the implementation: *"Fun, but felt like the motor struggled and the calibration wasn't good enough"*.

Figure 9.8. Prototype #1 being tested by one of the participants

Positive impressions

The next question asked about what they liked best about the prototype, where the participants had many different opinions. Some specifically said the use of balance was what they liked the most:

- *"The control was very intuitive once I got going"*
- *"The whole prototype was good - The feedback on body movements was very intuitive"*
- *"Very easy and intuitive"*
- *"Everything, the whole concept – The balance control, motor, skateboard, really cool"*

Many participants found the fact that it was an electric skateboard in itself to be the best thing:

- *"The fact that it goes on its own"*
- *"Automatic propulsion"*
- *"That it's a skateboard that drives by itself"*
- *"The fact that it goes forwards and backwards without having to move my legs other than weight shifting. Fun when you also get the turning right"*

Others mentioned specific design attributes, or the speed and responsiveness of the prototype:

- *"I liked the lights a lot and the fact that you could go as fast or as slow as I wanted"*
- *"Speed and response"*
- *"The design, color of the wheels and the way it's controlled"*

Negative impressions

In terms of difficulties or things the participants thought should have been different, the responses were mixed, but many listed the technical issues we have already mentioned such as start-up performance or braking:

- *"Braking was a little stuttering"*
- *"More sensitive braking"*
- *"Would have been really nice if the lag in the beginning was gone, smooth acceleration"*
- *"A little too much throttle in the beginning"*
- *"Slightly too difficult to go slowly – had to use a lot of weight to reach top speed. Braking was a little too difficult"*

Several participants mentioned that turning was particularly hard as well:

- *"Turning was difficult at first, but I learned it eventually"*
- *"Turning is difficult, but I think it will be easier over time"*

Others thought the balance interface could have been better:

- *"The balance interface was good, but there's room for improvement"*
- *"The balance control was maybe not sensitive enough"*

Technical issues and limitations

The final question let the participants' list technical problems they experienced. Problems listed here included motor, balance and speed related issues:

- *"The motor stopped on several occasions"*
- *"The motor lagged and cut off"*
- *"Difficult to register weight changes"*
- *"At times difficult to reach top speed"*

Some also found the activation and calibration process too slow or inaccurate, where the board waited for the rider to step onto the board completely with both feet before calibrating and initiating driving mode. Prototype 2 especially had this problem, which was a result of a slightly misaligned load-sensor (this happened before the load sensor stopped working all together). Additionally, one participant experienced a full malfunction of the first prototype: *"At some point one of the boards 'hung', and when I tried to start it again it just made noises and the lights lit red"*.

Quantitative questions

The quantitative questions were more specific to different aspects of the prototype, such as ease of use, intuition, learning and fun. The questions were mainly 7-point Likert-scale questions ranging from *"strongly disagree"* to *"strongly agree"* (in calculations these were assigned values of 1-7) where participants could rate to which degree they agreed with various statements related to the balance interface and the prototype. The first set of questions were concerned with balance as input in general and were worded as follows *"Using balance to control the prototype was [aspect]"*, and participants could state to which degree they agreed with the statement. The next sets of questions were concerned with how balance was implemented in this particular prototype. As can be seen from the results (summarized in Table 9.2), the participants were overall very positive to these aspects. In particular, fun, intuition, easy to learn, user experience and overall satisfaction gained consistently high ratings. Some ratings showed larger variations than other, such as technical issues (here, it is possible that some participants misinterpreted this question as to mean that a high rating, e.g. *"agree"*, meant a low amount of technical issues) and previous skateboard experience, indicating a somewhat diverse sample in terms of skating experience. Responsiveness, precision and accuracy were also slightly more varied. The lowest means, while still all above 5 out of 7, were given to easy of use, accuracy and responsiveness. All results to these questions can be seen in Figure 9.9, Figure 9.10 and Figure 9.11.

Table 9.2 Results from all quantitative questions

Question	N	Mean (1 – 7)	SD
Fun: Using balance to control the prototype was fun	17	6,65	0,61
Intuition: Using balance to control the prototype was intuitive	17	6	0,94
Ease of use: Using balance to control the prototype was easy	17	5,24	0,9
Easy to learn: Using balance to control the prototype got progressively easier	17	6,47	0,8
Accuracy: Balance to control the prototype was registered as I expected	16	5,56	1,26
Precision: Balance to control the prototype was precise enough to drive in desired speed	17	5,71	1,31

Question	N	Mean (1 – 7)	SD
Easy to understand: I quickly understood how the prototype reacted to my movements	17	5,82	1,07
Responsiveness: The interface was very responsive to my movements	17	5,41	1,42
Controllability: I eventually gained good control over the prototype	17	5,71	0,92
User Experience: I got a good overall user experience with the prototype	17	6,35	0,86
Technical issues: I experienced technical difficulties with the prototype	16	3,06	2,21
Previous experience: Rate your previous skating experience	17	1,82	1,55
Overall satisfaction: Rate the overall prototype satisfaction	17	6,06	0,97

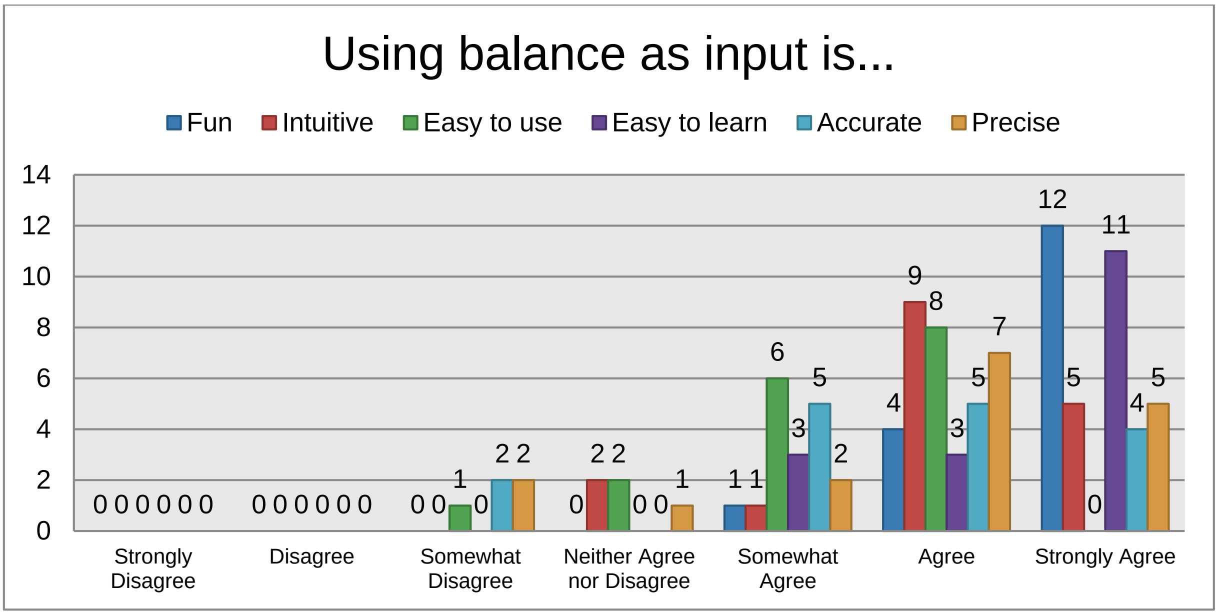

Figure 9.9 Quantitative results on balance as input

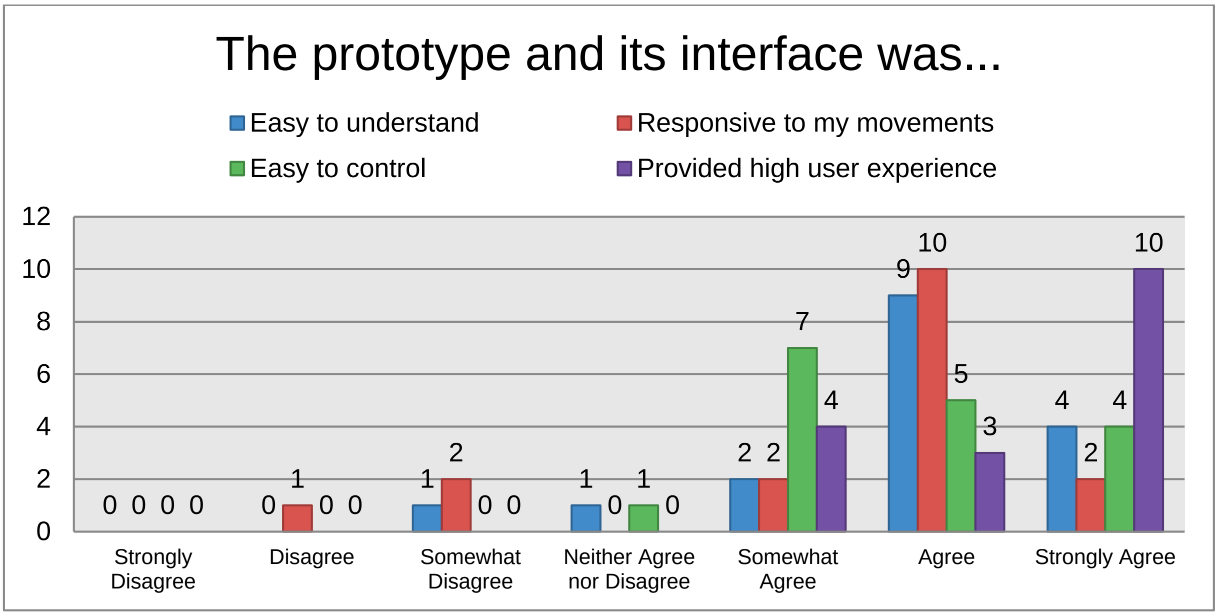

Figure 9.10 Quantitative results on the prototype and its interface

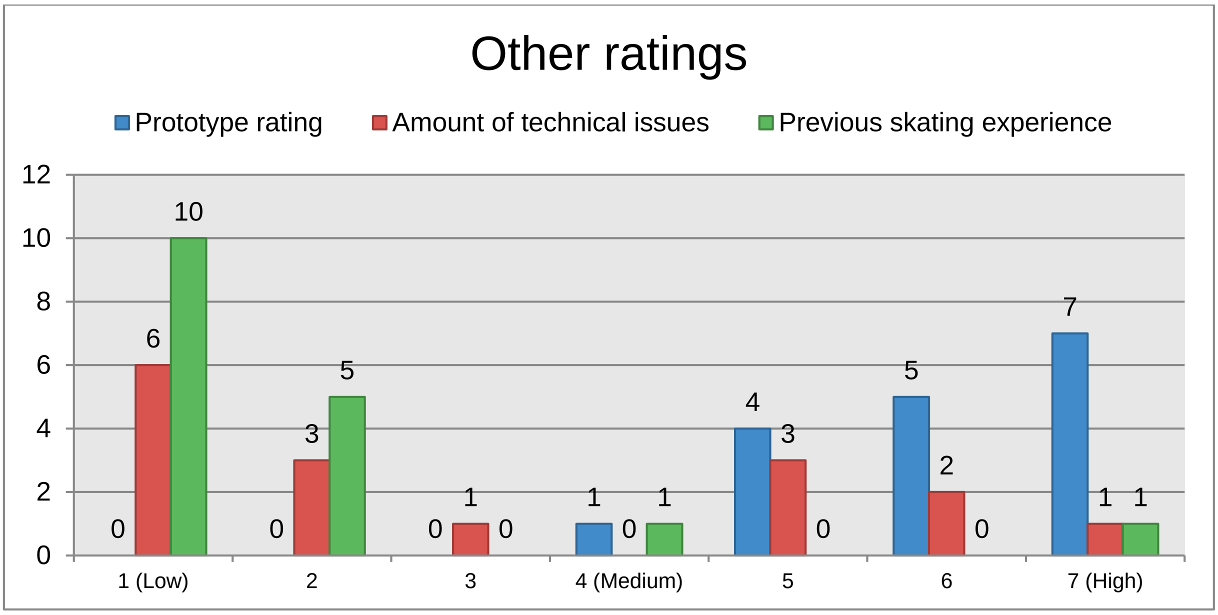

Figure 9.11 Various ratings on a scale of 1 - 7

9.3 Validity

From an interpretive point of view, validity is not concerned with a one-to-one measurement of objective reality as in positivism. Instead the framing of the research question, how respectfully the inquiry is carried out, how pervasively the arguments are developed and how widely the results are dispersed become much more important issues (Angen 2000, p.387). In relation to the prototype evaluation, there are several potential issues of validity. First, the majority of participants were students, and their characteristics are likely to inflict systematic errors into the results. For example, they were all in a similar age group (most were in their 20s), were educated, and they were likely to be more interested in technology than the intended target user. Because of this, the results are of limited generalizability to the target group as a whole. At the same time, the participants were in fact all within the target population, ideal in terms of age, and we would argue that they are good representatives of one of the core target users. Moreover, since our epistemological foundation is based around phenomenology, we do not consider the issue of generalizability to be a significant problem for our research, as phenomenology is not suited for generalizing in the first place. The number of participants (14 for the first test and 17 for the second), we consider sufficient for user testing the prototype in its current state. We think the technical issues that were identified should be ironed out to get the most out of additional tests in the future.

Another validity concern is related to the interpretive nature of the research. Since the findings are largely based on interpretations of what the participants have said about their experience interacting with the two prototypes, there could be conflicting understandings of the topics discussed between the participants and the researcher. For example, the participant and researcher may have vastly different understandings of what constitutes ambiguous terms like *'easy to learn'* or *'intuitive'*. Here, the informal discussions were used to try to uncover these potential difference by asking participants to elaborate and explain their perspective in more detail, but these differences may still be a source of inconsistent or diverging meaning of the terms, both between the researcher and participants, and between the various participants.

The presence of a researcher, who in this case also happens to have constructed the prototype for the evaluation, is also almost certainly a source of bias that will distort the participants' opinions towards the prototype. They may refrain from saying things they dislike and focus more on the things they think are good, in fear of offending or hurting the researchers' feelings. While we strongly encouraged and asked about negative aspects of the prototype, this has almost certainly skewed their feedback, and it should be expected that the results are more positively skewed than if the participants had been tested by someone not involved with the study. Nevertheless, self-reflexivity in interpretive research should not be an attempt to create an objective distance to the research topic, but to value the researchers contribution to the understanding, and to trace how the researchers sense of the topic changes over the course of the research (Angen 2000).

9.3.1 Ecological validity

There were several ecological validity issues in the first user test. The study was conducted in a controlled environment indoors in a hallway with a completely flat and leveled low friction floor. The hallway was long (over 100 meters) and quite wide (around six meters) so the participants had decent space, but making a full U-turn was difficult. Overall, this test can be said to have the ecological validity similar to that of an experiment, with few external disturbances allowing the prototype to be tested under controlled conditions.

In the second user test, the study happened outside on both concrete and asphalt surfaces. Most of the test area was flat, but there was also a small inclined area to test the prototype under uphill and downhill conditions. Since there were people walking by the area, the participants also occasionally had to dodge these pedestrians. The test area was also larger than the first test, with both a long area similar to the hallway for testing acceleration, as well as a larger open area for testing turning. In short, the ecological validity of this final user test, while not the perfect city conditions with traffic and urban obstacles, was much higher than the first test. To test with increased ecological validity than in the second test, the natural next step would probably be to test in actual city conditions on sidewalks and bike roads. In those conditions, there are safety concerns, both the participants and other road users, which we consider very problematic when testing using unfinished hardware.

9.4 Reflection on stage 4

In the final evaluation stage of the design life cycle, our research revolved around two usability tests, one formative and one summative, that included qualitative observations, informal discussions with the participants, and the completion of a paper survey following the tests. We were able to find answers to the questions we had regarding the prototype and as such, the evaluation stage has been successful, but some areas show room for improvement. Perhaps the main issue was a result of the implementation stage taking much longer than expected due to various difficulties with prototypes. This certainly affected testing time, and additional tests in additional prototype iterations would have been conducted had more time been available.

In this stage, a more long-term approach by lending out the prototype to a few participants over the course of several days was also considered. This would allow them to use it as a daily means of transport and report back on their experience with it in a user diary. Diaries are primarily a method used when participants are scattered or unreachable in person (Preece et al. 2011, p.338), but in this case it would be useful to study participants on the move without disturbing their daily transportation habits. Using this method certainly had the potential to return interesting insights into more context of use related questions, however due to legal and safety issues with the prototype that were virtually impossible to overcome, we were unable to continue to with this approach at this time.

10 Analysis

The following chapter includes our mixed-method analysis of the results gathered in stage 4. The analysis is structured around the six aspects from the theoretical framework described in Chapter 4, and the framework is used to interpret the results from the two tests. As only the summative test included a fully functional balance user-interface, we will put more emphasis on these results in the analysis.

10.1 Intuition

Several participants specifically said that the control felt intuitive to use, both in the survey handout and through informal discussions, and others said it was *“surprisingly easy”*. Further, since the vast majority of participants on the question specific to intuition agreed to some degree that using balance to control the prototype was intuitive (see Table 9.2), this suggests that balance to control a PMD, at the very least, is a viable approach even for beginners. However, the results are not unambiguous. Some participants had trouble with the interface, especially in the beginning, and the remaining two participants neither agreed nor disagreed with the claim that balance felt intuitive to control the prototype. This could mean that the intuitiveness of a balance interface is dependent on the users previous balance skill and that people with a poor sense of balance will struggle more. It could also mean that the sensitively, accuracy, or feedback, etc. within the specific implementation used in the prototype is not adequate and should be improved. Feedback in particular could have been a challenge as the prototype would register balance changes without tilting and some people may find this more difficult. Another possibility is that the subjective and highly personal nature of balance will intrinsically result in variations to how intuitive it is perceived.

Another question is if the intuitiveness of balance allows this approach to be favored compared to traditional means of control, such as a handheld app or controller. Although the results indicate that this could be the case, they are inconclusive and further testing is necessary. A very interesting view by one of the participants who tried both control modalities was that she found that her attention was too focused on the handheld controller, which took away from the experience of riding compared to using balance. This may suggest that balance is a better approach, perhaps in particular for beginners where using a handheld controller may demand too much attention, which ties in to the cognitive load required for postural control as described in Chapter 2.2.1.

10.2 Learnability

To see a clear difference in skill level according to Dreyfus’ model of skill acquisition, more time is needed, but through observations of the participants there was a noticeable improvement in skill even after only a few minutes, and most participants seemed to also have this experience.

The participants who made comments on aspects related to learning generally said that it became easier and more fun once they got used to it. Only about two or three participants struggled throughout the whole test, and it seemed to be the tilt of the board when turning that gave them the most problems. This was largely confirmed through their comments on turning difficulties versus difficulties with acceleration, where more people had trouble with turning. While it is possible that tightening the turning radius slightly would make this easier for beginners, it could also indicate that the tilt of the board in this regard is both a blessing and a curse. The tilt provides the rider with more feedback on their balance movements (we will return to this in the feedback section), but simultaneously makes it more difficult for them to keep their balance on the board. Additional tests are required to investigate this further to find an optimal feedback-to-stability ratio.

The participants rating of the learnability of the prototype was very high with a mean score of 6,47 out of 7 (see Table 9.2), and all participants agreed to some degree that riding became easier during the test. Still, as most people only tested for 5 – 10 minutes, it is difficult to say conclusively that the prototype has high learnability. The results do however strongly point in the direction of an easy learning curve initially for beginners.

10.3 Feedback

As described in the framework, immediate feedback is important to facilitate the development of intuition. Additionally, feedback is especially important in a balance UI that does not tilt in all directions. Only a single participant explicitly brought up feedback when describing his experience with the prototype, where he described the feedback on his movements as one of the most positive aspects of the prototype making the interaction more intuitive. Other participants brought up the related terms responsiveness and sensitivity. Responsiveness was considered to be good while several participants wanted the interface to have slightly higher sensitivity, i.e. less movement required to get more output from the prototype. This made it especially difficult for some participants to reach high speeds because they had to distribute a lot of weight forward to reach those speeds. Another complaint mentioned by one participant was that it was also difficult to go slowly. However, if going both fast and slowly is considered difficult, this suggests that there is room for improvement in the responsiveness as well, and not just the sensitivity. Higher sensitivity would make it easier to go fast, but this would also make it more difficult to go slow, because a smaller range of movements will allow the prototype to hold a constant slow speed. This suggests that there is room for improvements in the responsiveness of the prototype to make it easier for participants to make small adjustments in weight distribution, and get an immediate feedback from the board to tell them if and how they need to make additional adjustments to their posture.

As mentioned in relation to learning, the tilt of the board seemed to cause problems for some of the participants when it came to turning, because it would tilt too easily causing the participants to become unstable when riding and wobbling from side to side. Additional testing with a tightened turning ability is probably needed to identify the optimal relationship between turn radius, feedback, and board stability. It is also possible that the situation would have been even worse had the prototype also tilted forwards and backwards (like self-balancing vehicles tend to do), but this is only speculation at this point. In the first test most participants preferred a one-dimensional tilt when turning, but since they did not actually test such an interface the validity of this result is questionable. For now, we can only say that board stability seems to be important and the effects of less board tilting should be investigated further.

Of the quantitative questions, the question on responsiveness is probably the most relevant in terms of feedback, i.e. was the feedback immediate? Most people agreed with the claim that the prototype was responsive to movement with a mean of 5,41. Still, this question received a little more dispersed responses than most other questions (SD = 1,42), and 3 people disagreed to varying degrees with this claim. Balance accuracy is another feedback related question, i.e. based on your input, was the output what you expected? The responses were somewhat similar with most people agreeing (mean=5,56), but there was also some differences in the opinions as well (SD=1,26). Finally, the issue of precision is also related to feedback, i.e. was the resolution of balance detection good enough to get a precise output from the prototype? Again we have a slightly more disperse responses than in other questions (SD=1,31), but also a slightly higher rating for the precision overall (mean=5,71). Overall, balance feedback, and perhaps particularly in terms of responsiveness and accuracy, score good but not great and show some room for improvement based on the results.

10.4 Reusability

Reusability refers to people’s ability to reuse skills in the interaction, and is an important aspect of NUI and if applied appropriately can short-cut the learning curve causing people to learn a task or interface quickly because they are already familiar with the core tasks. As humans we rely on our balance skills all the time, when standing upright, walking, cycling, and when preventing ourselves from falling while standing on a platform that change its momentum. Clearly, the balance skill is an important part of being able to interact successfully with the prototype, especially seeing as balance plays a major role in skateboarding to begin with. But it is difficult to interpret the reusability factor based on the gathered data alone. Even the participants themselves probably don't know to what degree their already acquired balance skills gives them better control of the interface, and as expected none of the participants made any comments specific to the reuse of skills.

However, there are results that point in the direction of reusability. First of all, one participant in particular expressed that she had terrible balance skills before starting the test, and she seemed to struggle quite a bit with finding her stability on the board and intentionally performing tasks like acceleration and turning. Additionally, the high ratings to the question *"I quickly understood how the prototype reacted to my movements"* which estimates the participants conceptual understanding of how the interface works and reacts to body movements, indicates that there was a match between what the participants expected from a balance controlled interface and what they experienced during the test. This is also consistent with the question *"Balance to control the prototype was registered as I expected"* which also received a high rating, but more evenly distributed. As balance is highly subjective and individual, it is expected that there will be larger differences in how sensitive they expect the interface to register movements. This could suggest that these individual differences formed by a life-long experience of relying on balance skills could potentially become an obstacle in designing a balance UI that works well for everyone.

10.5 Affordance

Since the prototype looks almost indistinguishable from a normal skateboard, the prototype should for the most part afford the same things a skateboard does. This will naturally afford different things to different people, but most people in the target group should have a basic understanding of how to interact with a skateboard, even if they lack any personal experience with one. Because of this, it was important to ensure that it was possible to interact with the prototype exactly as if it is a normal skateboard, with only the added features related to automation. Further, it was important that these added features were implemented the way people would expect them to work. Skateboards naturally turn using balance, thus already afford the use of balance in the interface. The prototype simply applies this concept in one additional dimension: forwards and backwards in addition to left and right.

The headlights and taillights are the main indicators that it is an electric skateboard, and many people walking by the test area realized this. The explicit instructions given to participants before the test were simply that it was controlled using balance and that you lean forwards and backwards to accelerate or break. With only these instructions most participants seemed to understand how to interact with it successfully and they could deduce how to, for instance, go in reverse from these instructions alone. This suggests that the way balance has been implemented is afforded by people as the natural and expected way to interact with it when they are aware of balance being the input modality. Since the interface was designed according to the NUI principle of invisibility, there are no visible indicators of balance as input before someone interact with it, but once they do, the prototype responds to balance movements with both visible feedback in the form of lights, and motion feedback with the drivetrain.

Interestingly, while the participants understood how to interact with the prototype from the simple instructions, it seems like they did not know how the interface had been implemented. When discussing the technical aspects of the interface with some participants, they guessed that the weight sensors were directly under their feet, or perhaps slightly closer together to the center than their feet. In reality, the sensors were located between the trucks and the deck, i.e. close to the outside edge of the board and wider apart than their feet. So even with a slightly inaccurate conceptual model of the interface, they could still interact successfully.

From the results, there are no indications of a lack of affordance with the prototype. People generally understood how to interact with it very quickly, which is confirmed by the high rating for the question *"I quickly understood how the prototype reacted to my movements"*. From the observation, the activation process seemed to be the only part of the prototype where people would occasionally interact incorrectly by trying to accelerate before the board was calibrated to their posture, and the comments confirm that some participants experienced this problem. Another issue and a potential problem was mentioned by one of the more experienced skaters, who explained that to them, breaking on a skateboard affords foot breaking, because this is what they do on a regular skateboard. This means that a skilled skateboard may have to unlearn foot breaking and learn to break by leaning back. This is therefore a potentially area where the skilled skater is at a disadvantage compared to the beginner or novice. We did not observe this causing a problem, but it is easy to imagine that it could lead to some unsafe situations, since skaters usually foot break with their back foot while their front foot is on the board, and this would cause the prototype to accelerate.

10.6 User Experience

The participants were generally very happy with the experience of riding the prototype, and the word *"Fun"* was frequently brought up in discussions and the qualitative responses. It was clear that the participants found the prototype enjoyable. Especially seeing as several participants tried it for an extended period or came back to try again. The quantitative rating for fun and UX also indicate a very good overall user experience. Based on the results, the things holding the user experience back seem to be mostly the need for a slightly more accurate balance interface, and the various technical issues experienced by the participants. These were mainly motor issues, breaking issues and some difficulties with the activation process. None of the participants were unhappy or frustrated with the prototype, but some pointed out aspects where they saw room for improvement, like the ones already mentioned. If we disregard issues with the specific implementation used in the test and instead consider the UX of

PMD balance interfaces in more general terms, the results indicate that such an interface has an excellent potential for being highly enjoyable.

10.7 Summary and findings

Presented in Table 10.1 is a summary of the analysis with seven key findings. We present one finding for each of the aspects from the framework, and two for the reusability aspect.

Table 10.1 Key findings of the evaluation

#	Findings	Aspects
1	The use of balance as input is generally perceived as an intuitive way to control a PMD, but there seems to be somewhat large individual differences	Intuition
2	A balance UI can initially have an easy learning curve with users showing rapid skill improvement early on	Learning
3	Tilt-based feedback was not found to be a requirement for providing the user with sufficient postural feedback	Feedback
4	There are indicators of balance skills being transferred over to the interaction with the interface	Reusability
5	Individual differences formed by life-long experiences of using balance skills are potential obstacles for designing a balance interface that works well for everyone	Reusability
6	Participants could interact successfully with the prototype from simple instructions and deduce how to perform certain actions without any explicit instructions at all, even with an incomplete mental model of the interface	Affordance
7	High user experience was achieved through the perceived fun and enjoyment of using balance as input	UX

In general, balance, as understood through all six phenomena from the framework, has proved to work well. It is perceived as an intuitive way to control a PMD and this intuitiveness is likely supported by the reuse of balance skills, through immediate and appropriate feedback on the riders’ body movements, and through the mediated affordances of the interface. The appropriate reuse of balance also helps in terms of learnability, making the interface easy to learn, at least initially. How the learning aspect continues over longer periods remains a question.

11 Discussion

In the following chapter, we will first address the three sub-questions and discuss them against relevant literature one by one. Our three sub-research-questions are:

1. Is it possible to design for intuitive interaction?
2. Is balance a viable input modality?
3. Is the theoretical framework useful as an evaluation tool?

Then, in Chapter 11.4, we return to the main research question of this thesis *“Can balance alone be used to control a personal mobility device in an intuitive way?”*, discuss the prototypes’ knowledge contribution and reflect on the study conducted.

11.1 Designing for intuitive interaction

Intuitive technology, as mentioned in Chapter 1.2.2, is often used synonymously with ease of use in marketing and in informal discussions. However, similar understandings of the term is also found in the literature (Nielsen et al. 2004). Several authors define intuitive interfaces as interfaces that can be used without learning (Hummels et al. 1998, p.2; Bullinger et al. 2002, p.4). Loeffler et al. emphasize the low mental effort requirement and define it as an interface where *“[...] the users’ unconscious application of prior knowledge leads to effective interaction”* (2013, p.1). In this study, the term intuition is defined through the theoretical framework as interaction that relies on tacit, unconscious cognitive processes and the reuse of existing human skills to facilitate an immediately understandable interface within a given context. With this definition, intuition goes beyond usability related terms like easy to use and learn. Instead, it must rely primarily on unconscious processes, as opposed to a reason-based or analytic approach. It must utilize either innate or already acquired human skills or capabilities, and these skills must be used in a way that is immediately understandable within the context of use. With this definition, it is difficult to see how any traditional GUI-based point-and-click style interface can be classified as intuitive, regardless of its ease of use and in stark contrast to what seems to be the typical use of the term.

Our approach for designing for intuitive interaction was largely reliant on designing for already acquired skills. This approach is not new, and a similar strategy was applied by Bullinger et al. (2002), where the authors present several prototypes and argue that intuitive interaction can be achieved through designing for natural or acquired skills or knowledge through a strong user-centered approach. Di Tore et al. (2013) argue for applying *enactive knowledge* for education purposes. Enactive knowledge is knowledge stored in the form of motor responses, acquired through action and made possible because of the spread of NUIs (Di Tore et al. 2013, pp.106–107).

As outlined in Chapter 4.2 (p.24), a high priority in this study was to design an interface for the capabilities of the human body, and to map body movements (input) to an appropriate set of prototype responses (output). We argued for this mapping in Chapter 2.2.1 (page 10) and explained why forwards acceleration is an appropriate response to the action of leaning forwards, something the participants all agreed with during the evaluation. Both Nielsen et al. (2004) and Larssen et al. (2004) also emphasize the need for appropriate mapping between the movement and function in intuitive interfaces through a human focused rather than technology focused interaction approach. Similarly, Hummels et al. (1998) found in their study on act gestures that the mapping between the gestures and their meaning was not one-to-one, and there were differences in personal styles with few inter-personal consistencies. In our study, we found some individual differences (finding #1), but these were preference differences in terms of how the lean is carried out, rather than a mismatch between movement and function, which was not observed in this study.

One of the rather interesting comments made by the participants during the summative usability test was from a girl who found riding the prototype much more enjoyable when she did not have to focus on using the handheld controller. With the controller, all her attention was on how to give the appropriate input to receive the wanted output. With the balance interface, giving the appropriate input was effortless and hardly required any thought, allowing her to focus on the activity rather than the interface. In the study by Moen (2007), the author found that the ability to imitate movement depends on previous experience with similar movements, personal physique and preference. By allowing movements that are in-line with the user’s intuitive movement patterns, they spent less time and effort figuring out what to do (how to give the system the desired input) instead of focusing on the task or activity. In this sense, we argue that designing for intuition means designing for the types of movement that are considered a natural way to move without any interface present. Accomplishing this task will cause the interface to ‘disappear’ (as with the invisibility concept described in Chapter 4, p.32) and the interaction becomes automatic.

Overall, designing for intuition was found to be plausible even when we apply our narrow definition of intuitive interaction. It seems that most authors agree that designing for intuition is possible, but it should be emphasized that there is no agreement upon the definition of intuitive interaction, and some authors even use the casual meaning of the term, which is similar to ease of use and learnability.

11.2 Balance as input modality

Our findings show that the participants generally liked using balance to interact with the prototype. It was considered a fun (finding #7), intuitive (finding #1) and easy to learn (finding #2) way to control the vehicle and the participants could interact beyond the explicit instructions (finding #6). The main challenge with this approach, based on the analysis, seems to be responsiveness, precision and accuracy. Fikkert et al. (2009) similarly found that most people considered the balance interface (using a Wii balance board) easier to learn compared to the handheld controller (Wii remote) for navigating a virtual maze. Additionally, they found that balance was considered more intuitive, and they indicated after the test that the balance interface was the most fun. Accuracy was rated higher with the handheld controller, and performance in respect to completion time was significantly faster. Overall, the results found by Fikkert et al. correspond very well with the findings from this study. It should however be mentioned that the technical issues such as poor low speed and breaking performance may have influenced these attributes more negatively than other attributes.

In relation to feedback from the interface (finding #3), this was found to be sufficient in the tested prototypes which provided feedback in the form of motion, LED lights, and side-to-side tilting like a normal skateboard. It should also be noted that prototype #2 did not have any lights, yet did not score any differently. This suggests that the feedback provided by the lights may not be necessary and that the motion of the board provides enough feedback on its own, even without tilting forwards or backwards. However, the participants were merely asked for their preference and did not get to actually compare a tilting (elastic) interface to a non-tilting (isometric) interface like Wang & Lindeman (2012) did. In their study, they found that the majority of participants preferred a tilting balance interface. The tilting interface was found to be more intuitive, realistic, fun, and lead to a higher level of presence, but had higher fatigue and after effects. The authors found no difference in efficiency and precision between the two modes. They suggest that a fully tilt-based leaning interface (i.e. also tilting forwards and backwards) could be perceived as more intuitive than a non-tilting interface. Based on the results of the formative usability test, a sideways tilting and straight non-tilting interface was preferred by the majority of participants, suggesting a conflict between our findings and Wang & Lindeman’s findings. There are multiple reasons that could explain this difference in results:

First, in Wang & Lindeman’s study, the interface is used in a VR setting, and an isometric setup provides no other feedback beyond what happens on the screen, unlike a tilting interface, which provides feedback to the human balance system (as described in Chapter 2.2). This is obviously not the case with this study’s prototype where acceleration results in feedback to the balance system through a change in velocity, thus feedback is provided without any tilting. Second, since the interface was used to control an avatar in all three directions (including up and down), leaning controlled the pitch of the board to increase or decrease altitude like an aircraft. This is different from the prototype where leaning controlled velocity rather than pitch, and it is not immediately clear why it would make sense for the board to tilt downwards while the velocity forward is increased.

An interesting result about the interface revealed through the summative test, which several participants talked about, was that leaning forwards and backwards to accelerate or break, was generally found to be much easier than leaning sideways to turn. This was especially common among participants without skateboarding experience. De Haan et al. (2008) found that leaning on each foot required a larger shift of balance and was slower than leaning on heels and toes thought their balance interface implementation. In the study, leaning on each foot was used to strafe or pan the camera view, leaning on heels and toes moved forwards and backwards, and turning the camera was done by pressing on heels and toes of opposing feet. Forward motion and turning was found to be intuitive and resulted in smooth movements through the environment. This difference in results could be caused by multiple factors:

When controlling a virtual camera, precise and instantaneous motion is achievable and this may not be easily comparable to controlling an accelerating platform that is gradually building up momentum. It is also possible that the sideways stance is encouraging a larger shift in weight distribution between the feet than a normal forward stance, and as such, leaning on each foot becomes easier. Further, it is possible that the implementation alone, which is quite different in de Haan et al.'s study, could explain the difference. Nevertheless, the participants in de Haan et al.'s study found the use of balance intuitive, which is consistent with finding #1.

In short, balance as input was found to be a viable interaction approach, but some challenges remain. Ensuring high responsiveness should be a priority and both precision and accuracy of posture, especially when it comes to individual differences, are the main challenges. Additionally, further technological innovation may be necessary to enable an interface with higher accuracy and responsiveness.

11.3 The framework as an evaluation tool

The theoretical framework employed throughout the study is based on the following three theories: Tacit knowledge, Dreyfus model of skill acquisition and the Natural User Interface. These were selected because of their relevancy to phenomenology, which is how we understand embodied experiences, and what our theoretical foundation is based around. Phenomenology has previously had a strong influence on embodied interaction within both HCI and interaction design and is used by several authors (such as Moen 2005; Loke et al. 2006; Larssen et al. 2007; Klemmer et al. 2006). One of the primary concerns of the framework is the reuse of balance skill where an important point is that the subjective nature of embodied interaction is predicted by the interface to avoid that differences in an individual's abilities will result in limitations in the interaction. A concrete example is that any stance on the prototype is as valid as any other stance. If a user's stance is perceived as evenly balanced, the technology should conform to the user and redefine what it considers 'in balance' (as described in Chapter 8.5.1, page 92), even if the input it receives in reality is far from even. Larssen et al. (2007) presented a way of looking at the *feel dimension* and what role the kinesthetic sense plays in HCI. Through their phenomenologically motivated approach, they introduced five aspects: *Body-thing dialogue*, *potential for action*, *within reach*, *out-of-reach* and *movement expression*. These aspects differ from our six in several ways. First, they are more concerned with which actions are possible at any given point and to an extent see the body as an interaction instrument that may be used in different ways depending on the subjects' own abilities. In short, Larssen et al.'s aspects embrace the notion that different bodies have different interaction potential. Our approach, as demonstrated in the example above, is quite different: Our aspects focus on providing *all* individuals the *same* interaction possibilities in the interface, regardless of what kind of body they have. We would argue that both of these two approaches are equally useful, but they are probably appropriate in different situations.

Another distinction we will point out is that Larssen et al.'s aspects revolve around manipulations of the subject's surroundings, such as moving objects, touching, and reaching. In this sense, these aspects seem more relevant to upper-body movements, but the aspects may also be applicable to our prototype. For example, when first stepping onto the prototype, the interaction takes place *within reach* of the user and this initiates the *body-thing dialogue* between the user and the board. This dialogue remains active as the user is interacting with the *thing* using balance, and the interaction is both enabled and restricted by the users' *potential for action*. When the user slows down and steps off the board, the interaction also briefly takes place *out-of-reach*, because the absence of physical contact is interpreted as a trigger to stop the motor and deactivate driving mode.

As the framework is relying on balance, it should be considered a full-body interaction approach where movement is both the input and the output. However, it is also more than that, because the input and output are working in tandem. For example, when a user riding the prototype becomes off-balance, the prototype readjusts to the users body posture, and will either speed up or slow down to help rebalance him. Thus, the user and the computer are working towards the same goal, but always on the users' premises. When the participants recognized this, they interacted much more freely with it, perhaps because they realized that the prototype is trying to help them remain balanced. Moen's (2005) approach, is almost identical, where he argues for a full-body movement interaction approach that also relies on both movement as input and output, but with dance rather than balance. Moen uses phenomenology and in particular Fraleigh's (1987) concept of the lived body as an interaction model to show the relation between *the self*, *the dance* and *the other* to inform the design of the BodyBug movement interaction prototype (described in Chapter 3.3, p.20). The author proposes that when computers tend to be more human-like in their behavior they can be considered *the other*. When we know the possible reactions the computer has to our movements, we interact with it accordingly and our expectations towards the computer become shaped by its embodiment and its *'body language'*. Usually, the user is considered the other, as it is he who must adjust to the interaction possibilities provided by the computer, instead of having the computer react to him. This relates well to the example described above. In this case, the user does not have to adjust to the movements of the prototype, such as leaning to compensate for a change in velocity. In fact, it is the opposite; they lean, and then *the other* reacts.

During testing, the participants largely learned how to use the interface through bodily engagement and practice, rather than through verbal instructions. Since the prototype responded to their movements largely as they expected, many of them learned quickly and got comfortable with the interaction after only a few minutes of use. In a paper by Klemmer et al. (2006), the authors present five themes for embodied interaction: *Thinking through doing, performance, visibility, risk* and *think practice*. One of the points argued for by the authors is the importance of exactly this kind of bodily engagement to facilitate learning. They say this approach allows a way of learning and understanding new concepts, which would not be possible through words alone. The authors also argue for the use of prototypes as a way to aid thought. Using artifacts and the *backtalk* they provide, help uncover problems that could not be revealed without producing an artifact. Additionally, the backtalk facilitates communication by *"providing a concrete anchor around which the discussion can occur"* (Klemmer et al. 2006, p.142). With the prototyping approach used in this study, this certainly helped fuel the discussion around something concrete during testing, and the participants contributed hugely with suggestions on both the prototype and its interface. However, the design of the prototype beyond the interface itself was of lesser importance to the study, which was much more concerned about the concept of using balance as input in general. Thus, the *backtalk* probably helped the most during the creation of the prototype as solutions to design problems were discovered through a *"conversation with the materials"* (Klemmer et al. 2006, p.142). The authors say this presents us with a different kind of embodiment, namely that they embody design ideas or specifications and render them concrete, which in turn informs the designers' thinking. The themes presented by the authors differ from our framework in that they primarily contribute to being helpful in the design process, rather than a way to measure and evaluate its result. As such, many of the themes they discuss nicely compliment the theoretical framework used in this thesis.

11.4 Balance as intuitive PMD control

In the discussion so far, we have discussed the applicability of intuition in user interfaces. Our definition of the term is arguably a more narrow definition than what is commonly considered intuitive, and is fully separated from usability related terms like ease of use. Nevertheless, designing for intuition, as we have seen, was found to be possible through appropriate use of existing bodily skills. These findings were compared to those of other authors, and found to be largely consistent. Then, we discussed the viability of balance as an input modality for mobility devices, which was found to be not only fun, but also natural and easy to use by the participants, showing that balance is a viable input modality, if not for some individual differences. Finally, we have established that the theoretical framework has worked to its intended purpose of guiding the prototype evaluation and in analyzing the results based on the six balance as input related aspects, and looked at differences and similarities with our approach to other phenomenologically motivated research. The framework is perhaps particularly useful because it incorporates intuition, which is difficult, but as we have seen possible to design for. Next, we will take a closer look at the most significant knowledge contributions generated by the prototype.

11.4.1 Knowledge generated from the prototype

Based on the participants' responses and interactions with the prototype, perhaps the number one knowledge contribution the prototype has provided is that interacting with a balance-interface is fun. This is based on the fact that virtually all participants reported having fun interacting with the prototype in both verbal discussions and in the follow-up survey (Mean=6,67 SD=0,66) and many did so over an extended period, and came back to try again after a break to let other participants test. Similarly, Wang & Lindeman (2012) also found that participants found interaction with their balance interface in a virtual environment fun and enjoyable, and Fikkert et al. (2009) found that participants preferred the balance interface over the remote controller in spite of lower performance.

Furthermore, the prototype has demonstrated that balance as input is in fact perceived as intuitive and natural to use. We base this on the observation that participants got the hang of using the interface quickly, could interact successfully and derive how to perform certain actions without any explicit instructions, such as adjusting speed by adjusting the amount of lean and go reverse by leaning in the opposite direction. They also reported high scores for intuition of the interface (Mean=6 SD=0,94), that their movements were registered as expected (Mean=5,56 SD=1,26), and that the interface was easy to understand (Mean=5,82 SD=1,07). Hummels et al. (1998) similarly found that motoric gestures are suitable for intuitive interaction because this approach allows us to afford possibilities and act related to our body and perceptual-motor skills.

A final key knowledge contribution is that the balance interface was easy to learn, despite technical limitations with our specific implementation. This is primarily based on the improvements in skill we witnessed after only minutes of use, even from people who have never skated before. While we do not yet know the long term learnability effects, it received high scores in the survey for the short duration of the test (Mean=6,47 SD=0,8) showing that participants experienced a significant improvement in skill after only minutes of use. This is an interesting result especially considering several authors that have investigated the learning effects of balance interfaces in non-mobility contexts have not seen similar effects (Wang & Lindeman 2012; Fikkert et al. 2009).

11.4.2 Methodological approach

In principle, answering the research question could have been achieved without designing or building any prototypes at all. For example, the assessment of balance as input in relation to personal mobility could have been accomplished through a simulation alone. Such a simulation could for instance be done using devices like the Wii Balance Board and Virtual Reality headsets similar to the study by Wang & Lindeman (2012) on comparing elastic to isometric balance interfaces. In such a study, since designing or prototyping is unnecessary, a vastly different methodological approach would probably have been more appropriate such as a case study.

In a simulation study, factors specific to the device and preferences in vehicle functionality could have been ignored allowing the core experience of controlling a vehicle using a balance interface to be the primary focus. While such a study could also answer the same research question, it would not provide a very realistic experience to the participants and there would likely be major problems when extrapolating from a simple simulation to an urban context. One can imagine assessing the intuitiveness, learnability, or feedback of a virtual vehicle in a virtual environment, and issues like stability, controllability or safety can hardly be assessed in a virtual environment at all. Another approach could have been to use an existing and already available balance controlled PMD (such as a self-balancing unicycle) as the testing device. Compared to a simulation, this approach could potentially be a much more ecologically valid study that could be tested in a real urban environment. The main problem with this approach however, is that it is difficult, if not impossible, to fully separate aspects related to balance, from aspects related to self-balancing. A participant testing balance as input using a self-balancing system will almost certainly be influenced by the self-balancing system. As a result, generalizing these results to non-self-balancing systems is problematic, because these devices differ in a number of ways and are, unlike self-balancing vehicles, inherently stable both when moving and when stationary. It seems that all currently available balance controlled PMDs are also self-balancing, and most of them only use balance to control acceleration, while turning is done with the handlebars. Thus, this approach would in reality be a study on self-balancing interfaces and not purely on balance interfaces. It remains to be seen if self-balancing vehicles is the right way to move forward in the PMD space, mainly because of their inherent instability and no clear advantage over inherently stable PMDs. The advantage of such vehicles lie primarily within the balance control, and as demonstrated in this thesis, the same balance control can be implemented independently of the self-balancing system.

Another option would be to build a functional prototype for the same testing purposes, but not through a user-centered approach. If the sole purpose of the prototype is testing its UI, then a genius-design methodology could also have been appropriate since much less time is needed to involve users into the process and identify their needs. This would in turn allow for more time to be spent on building and testing the prototype UI. This approach, while certainly also viable, would risk the development of a prototype and UI that did not meet the users expectations and could more easily suffer from usability problems or poor UX. Furthermore, a problem arises when the genius-design UI is tested with users and not found to be intuitive, easy to learn or use. The question then becomes whether the problem lies within the specific implementation or if it is a problem with the concept of a balance interface in general.

11.4.3Theoretical framework

In general, the theoretical framework employed in this thesis have provided a theoretically grounded description of the rather intangible concepts of intuition in the context of balance as input and categorized related topics of interest like learnability, skill reusability, interface feedback and affordance. In this sense, the framework has been useful and has helped focus the inquiry on a selected set of topics that can shed light on the balance UI from different angles. However, actively applying the theoretical concepts associated with each phenomenon has been a challenge as there is no easy way to measure them.

While the theoretical framework was primarily a tool intended for evaluating the research question, to some degree it has also been helpful when designing the prototype and its UI. For example, the UI has since its inception been designed with intuitive movement in mind so that if, for example, a novice rider needs to suddenly break to avoid collision, the immediate bodily response is to back away from the situation. This predictive action of leaning back will initiate the breaks without the rider consciously determining the appropriate action. Another example is affordance, where the prototype and its design should afford possible actions simply by the way it is designed. The invisibility NUI concept in particular had implications for this part of the design where the weight sensors are completely hidden, creating the illusion that the entire board, not just the two points, detect pressure changes.

However, for the most part, the framework was used through the final evaluation stage of the design life cycle and primarily in the summative test, to make balance aspects of interest explicit. The framework combined the three theories into a set of six different phenomena related to intuition and used these as a starting point for the topics to explore in detail.

Some of the findings that were identified were only partially covered by the framework. These were primarily some of the challenges participants had with the interface, such as balance precision and responsiveness. In hindsight, a greater emphasis on uncovering such difficulties should probably have been included in the framework in more direct way. As it stands, these topics were included as feedback-related topics, since precision results in a decrease in feedback resolution, and responsiveness results in feedback delay. Still, the framework did not specifically concern these mapping problems, but probably should have as these are also points brought up by other authors (Hummels et al. 1998; Larssen et al. 2004; Nielsen et al. 2004), thus we consider this the main weakness with the framework.

12 Conclusion

In this thesis, the goal was to explore six aspects of balance-based interaction outlined in a phenomenology-based theoretical framework. Specifically, we wanted to determine if balance as input is perceived as an intuitive way to interact in a mobility context. Personal mobility devices were selected as the device category for answering this with the following research question *“Can balance alone be used to control a personal mobility device in an intuitive way?”* Applying a user-centered approach, we gathered user needs through a needs analysis consisting of an online survey (N=248) and existing statistics from multiple research rapports. Using a focus group and design workshop (N=7), an evaluation of similar designs, and paper prototyping, a PMD prototype with a balance interface was designed and then constructed. Through two usability tests (N=31), participants evaluated the resulting prototype against criteria from a theoretical framework with a special focus on intuition, skills and learning through the context of balance as input.

As demonstrated through the analysis, a rider of a personal mobility device can use balance, and nothing but balance, to control the vehicle intuitively. Furthermore, the interface was rated as being easy to learn and understand, with good feedback on body movements and providing excellent user experience to the test participants. It should however be emphasized that several obstacles have been identified, where the main ones are individual differences as to how intuitive the interaction is perceived, and issues regarding the precision and responsiveness which may require more sophisticated technology than what has been used in this thesis. Furthermore, it should be pointed out that testing of the prototype happened over a short time span, thus the data on the learnability of the interface is limited.

12.1 Contribution

In this thesis, several contributions are presented. First, we present a theoretical framework for evaluating balance as input in HCI research. Second, a new design with a new form of interaction has been demonstrated. This goes beyond the two prototypes that were built for testing purposes and represents a new solution to PMD interfaces in general. Through user testing, we have further demonstrated that the prototypes have intrinsic value regardless of the knowledge they have generated towards the research question. Third, we present our list of seven findings discovered through the framework, which provide useful results on balance-based interaction, and may be applied in future research or in future commercial products. These findings may also have implications beyond the skateboard PMD form factor. A final contribution of this thesis is a paper on the implications of NUI based PMDs with a balance interface, published by Springer and presented at HCI International 2015 (Rem & Joshi 2015).

12.2 Future work

A few different areas are highlighted which are seen as particularly beneficial for further investigation. Perhaps most importantly is the need for more detailed user testing of the prototype interface, but this should also be done once the technical issues have been eliminated so that they do not taint the participants’ experience. The sample size used should be increased and should consist of a more diverse group of people. More attention should be put on the perceived intuitiveness of the interface under different and more challenging conditions, such as an actual urban environment. Will participants be comfortable using the prototype on narrow sidewalks and bike roads close to traffic? What about more extreme up-hill or down-hill conditions? Is it perceived as safe? Is the braking performance good enough? These and other question are questions that currently have not been sufficiently answered, and rely on a prototype interface that does not suffer from the issues of the current prototype. Thus, it would also be necessary to build a third iteration prototype. Additionally, it should be determined if the framework is applicable in other research areas of balance based interaction beyond personal mobility. Perhaps the framework is equally useful in gaming, virtual reality, or other contexts where lower-body interaction is appropriate.

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14 Appendix

Appendix A Survey results by device type

A.1. Segway attributes

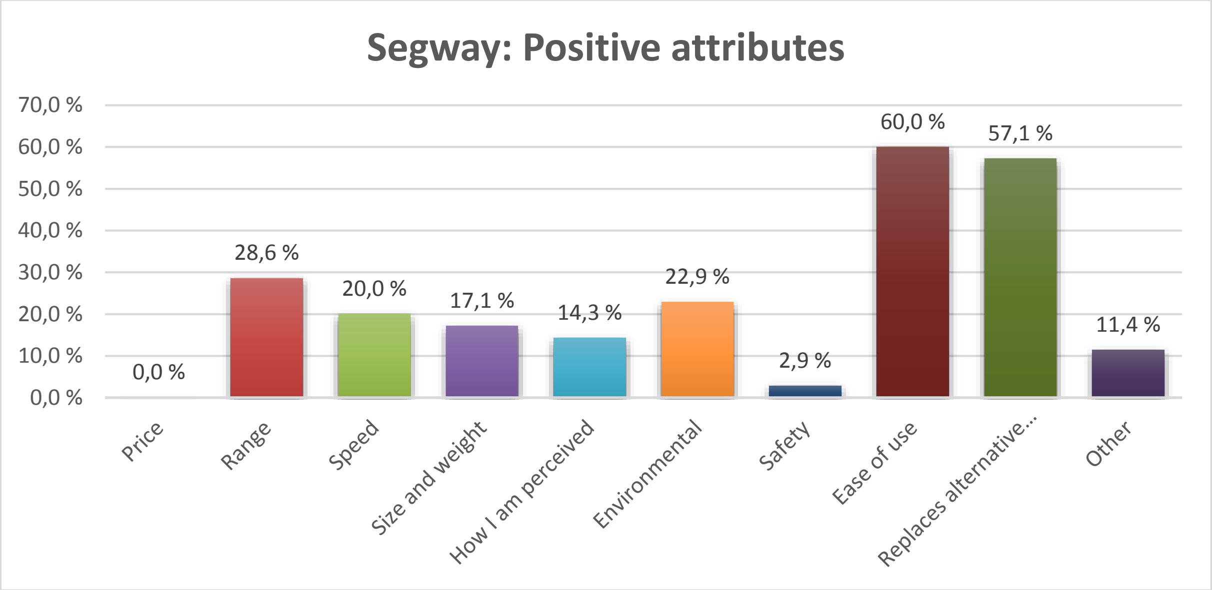

Figure 14.1. Positive cited attributes of the Segway

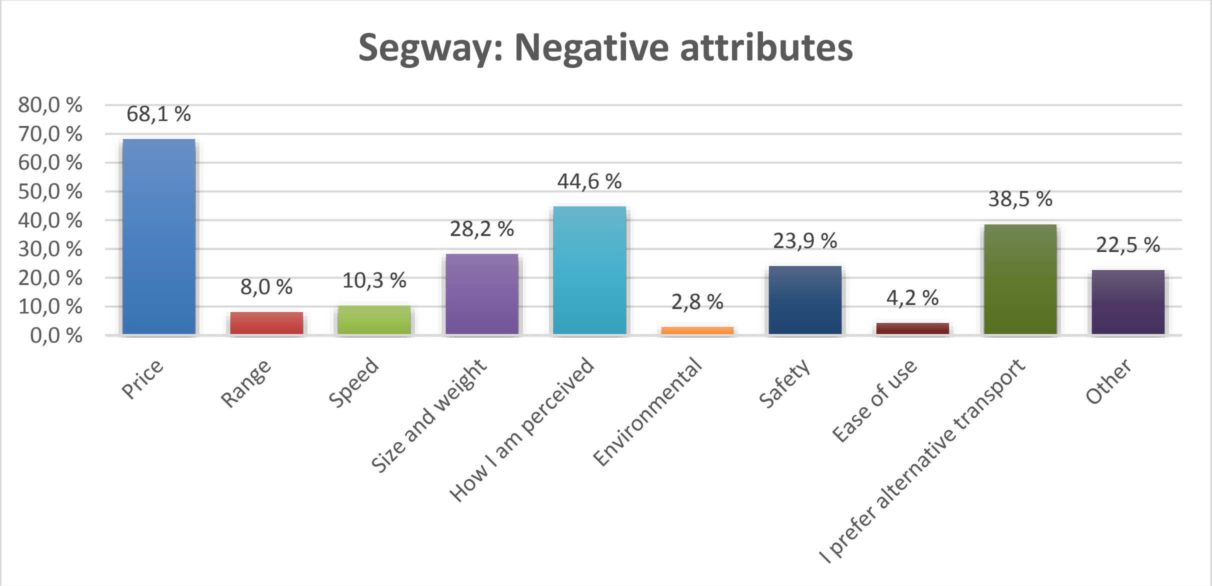

Figure 14.2. Negative cited attributes of the Segway

A.2. E-bike attributes

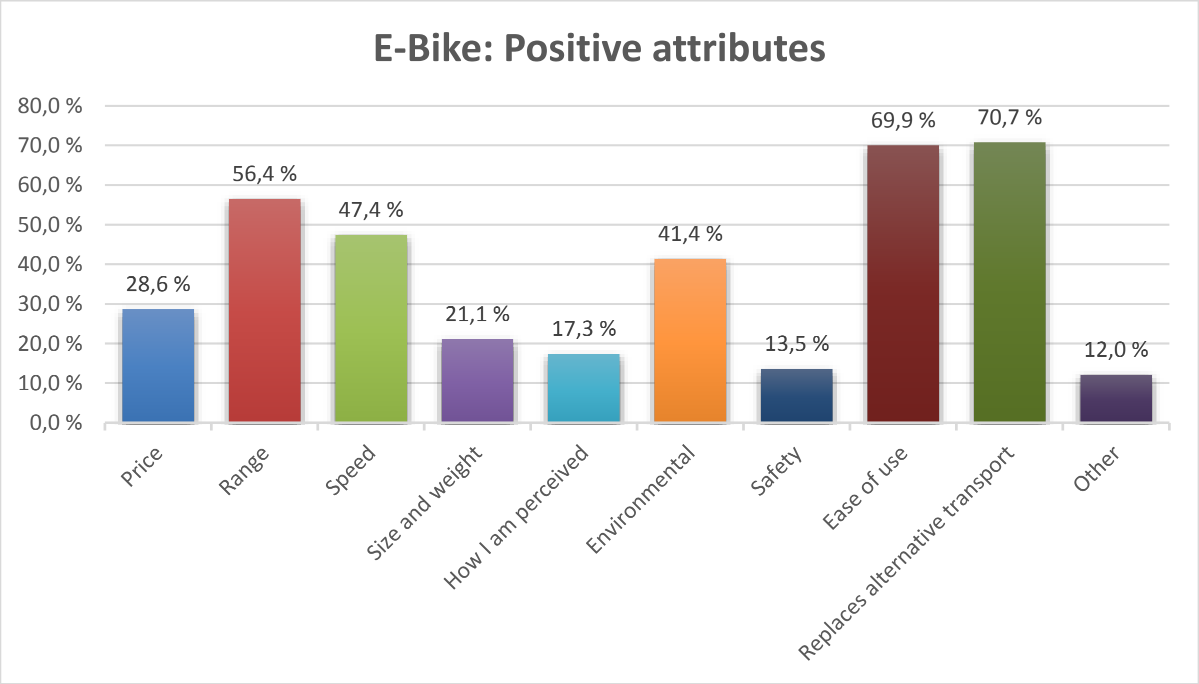

Figure 14.3. Positive cited attributes of the e-bike

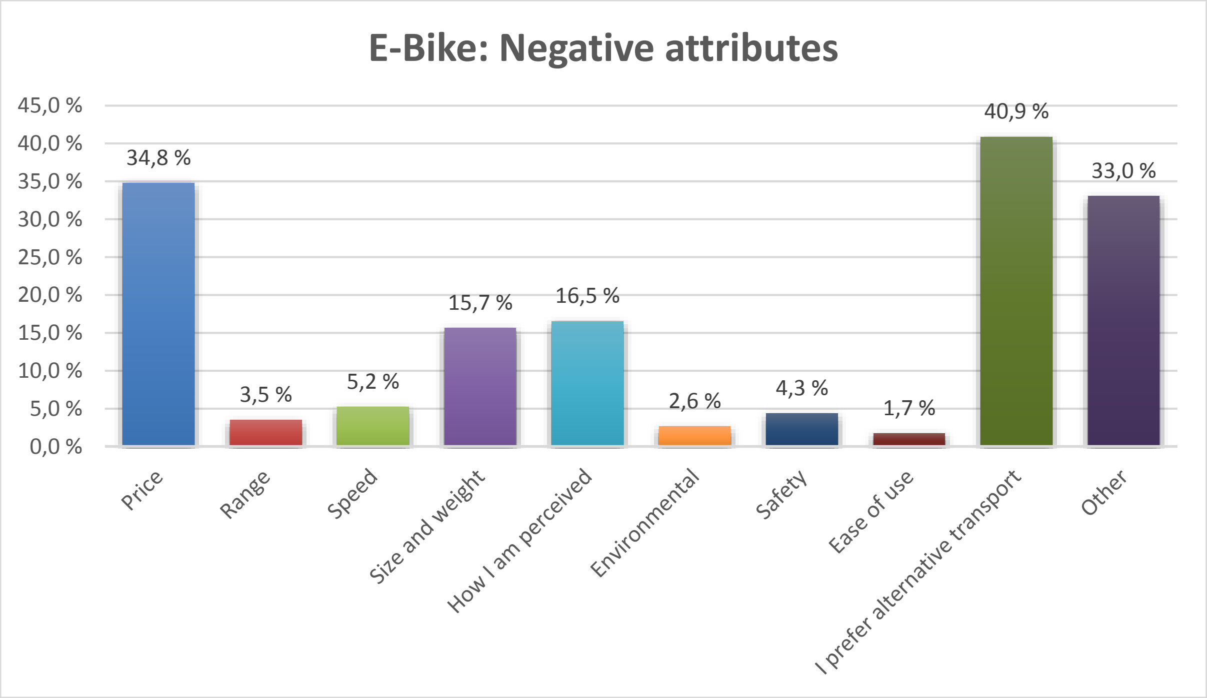

Figure 14.4. Negative cited attributes of the e-bike

A.3. Electric scooter attributes

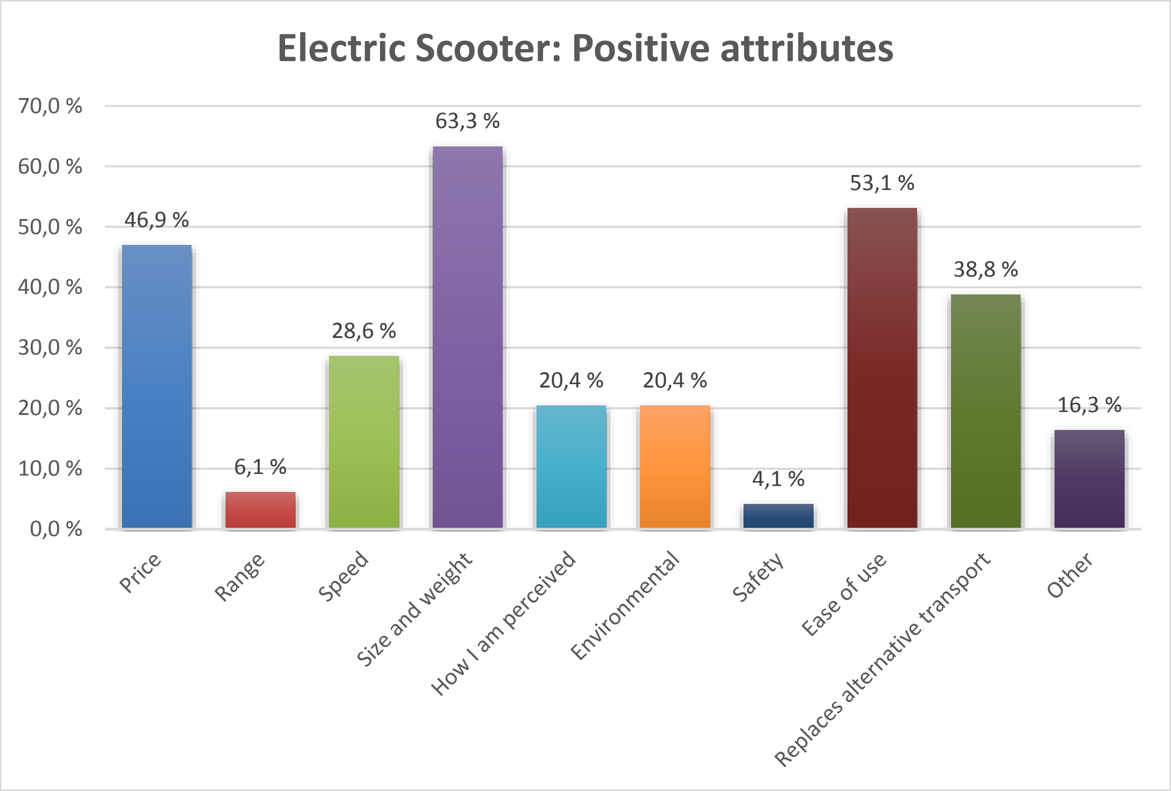

Figure 14.5. Positive cited attributes for the electric scooter

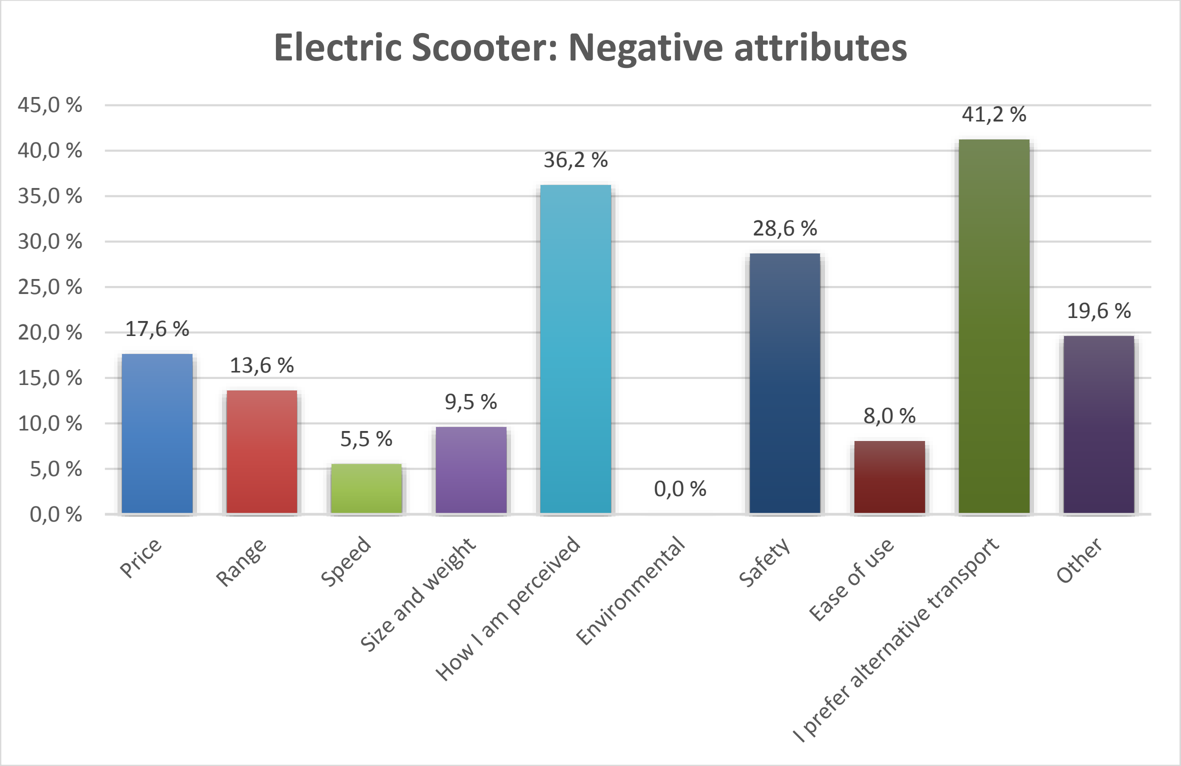

Figure 14.6. Negative cited attributes of the electric scooter

Appendix B Investigation of similar solutions

The following sections described the investigation of similar solutions from stage 2.

B.1. Boosted Dual+

One of the most high-end electric skateboards currently available is the Boosted Boards series. Funded on Kickstarter, their most powerful model, the Boosted Dual+, features a drivetrain of 2000 watts consisting of two brushless DC-motors. This gives the board a max speed of 35 Km/h, and enough torque for 25% grade uphill climbing. The battery is a Lithium Iron Phosphate (LiFePO4) 99W hour battery giving 11 km of range on a single charge. The board is controlled using a handheld wireless remote for acceleration and breaking and features regenerative braking to recharge some of the power back into the batteries. It weighs 6.8 kg and has a price of $1,499, but cheaper models with less power are also available.

Figure 14.7. Boosted Dual+ by Boosted Boards

With a low profile and two small cases that hold the battery and electronics are mounted under the board, the look close to a normal longboard. The dual motors are mounted to the back trucks and are hidden under the board as well. This design keeps ground clearance high and enables the flexible fiberglass-reinforced bamboo laminated deck to bend which absorbs vibrations and bumps and provides a smoother riding experience.

B.2. LEIF eSnowboard

The LEIF board is has a unique design that allows it to skid/carve sideways like a snowboard and is actually advertised as an electric snowboard for all seasons. It has two brushless motors of 2000 watt each that provide a speed of up to 32 Km/h and a 15% grade maximum incline. It has a range of about 13 km from the lithium phosphate battery and weights 6.8 kg. Speed is controlled with a handheld wireless remote, but braking is accomplished like on a snowboard when carving where the friction of the wheels going sideways does the actual braking. As of this writing it is only available for pre-order for $1,299, with expected delivery June 2015.

Figure 14.8. LEIF eSnowboard by LEIFTech

To enable the board to feel like snowboard carving through fresh powder on the pavement, the board uses two additional wheels under the board that can rotate in any direction (inspired by…?). The two motors are not connected to the longboard trucks like most other electric boards, but instead are attached the additional rotating wheels. The board has two bindings for the rider's feet to help them stay on the board as they're carving, and the battery actually is placed on top of the board between these bindings.

B.3. Marbel board

Marbel is another high end electric skateboard funded on Kickstarter. It is powered by a single 2000 watt brushless motor and has a top speed of 40 km/h and enough torque for riding up a 20% grade incline. It features regenerative braking and has a range of up to 19 km from the 165 Wh Lithium-Ion battery. The weight is only 4.5 kg and Marbel claims that makes it the lightest electric vehicle in the world. Throttle is controlled with either a wireless remote or with a smartphone app. This board is currently also pre-order only, with a price of $ 1,299 and expected shipping in May 2015.

Figure 14.9. Marbel skateboard by MARBEL Technology

What sets Marbel apart from other electric boards is that it looks almost indistinguishable from a normal longboard, with no external case for the battery and electronics. Everything except the motor is built into the carbon fiber and Kevlar deck, allowing the board to be very thin and light. The motor is mounted to the back truck and hidden under the board.

B.4. ZBoard and ZBoard 2

The ZBoard is probably the board that is the closest to our concept, as it is controlled without an external controller. The ZBoard instead uses foot pads on the front and back and will accelerate when pressure is applied to the front pad and brake when pressure is applied to the back-pad. However, compared to many other boards on the market the ZBoard stuck out as being considered “old tech” with only a 400 watt brushed DC-motor, a big and bulky battery, large rubberized off-road wheels and a relatively high weight (11 to 15 kg depending on model).

Figure 14.10. ZBoard Classic by ZBoard

The ZBoard 2, announced in January 2015, is a modernized version with the same foot pad interface. By replacing the brushed motor with a 500 watt brushless setup, a physically smaller battery with a range of either 25.7 km or 38.5 km, and a total weight of 7.3 to 8.2 kg, the ZBoard 2 is a big improvement.

Figure 14.11. ZBoard 2 blue by ZBoard

The design is similar to most electric skateboards with a case for the battery and electronics mounted under the board and a motor attached to the back trucks. The most notable difference is of course the two foot pads for throttle control. It also features handles on each side of the deck for easy carrying and head and tail lights. A battery LED indicator is located at front of the deck to easily keep track of when the board needs to recharge.

B.5. Onewheel

Onewheel is, at least in terms of its user interface, also quite similar to our prototype. It is a self-balancing skateboard with a single wheel and is controlled using balance. It uses a 500 watt transverse flux hub motor to get a top speed of 19 km/h, and a Lithium Iron Phosphate (LiFePO4) battery with a range of 6.5 to 9.5 km depending on riding style. It weighs about 11 kg, and costs $1,499.

Figure 14.12. Onewheel by Future Motion

The Onewheel looks almost nothing like a skateboard, with its large go-kart sized wheel in the middle of the board that allows it to drive off-road and over smaller obstacles. It is controlled similar to a self-balancing unicycle, except with the rider in a sideways posture. Acceleration and breaking is controlled by leaning forwards or backwards, and turning by pressing on heels or toes. The motor, battery and electronics are all integrated into the board, and it features headlights and taillights.

Appendix C Raw data from formative test

This section includes the raw data from the formative test (Also attached as excel file).

No	Previous Board Experience	Start acceleration	How to break	Tilting	Satisfaction
1	1	60,0	Legge vekt på bakre fot	2	7
2	2	58,0	Legge kroppsvekten på bakbeinet	2	6
3	4	70,0	Lene seg bakover	1	5
4	3	65,0	Legge vekt på bakre fot	1	7
5	4	60,0	Lene seg bakover	2	7
6	1	80,0	Vekt på bakre fot	2	6
7	5	60,0	Bakover (vekt på bakfoten)	2	7
8	2	70,0	Lene bakover, 70% - 80%	2	5
9	2	75,0	Lene seg bakover	2	6
10	7	60,0	Legge vekta bakover, men litt spektisk	2	5
11	5	63,2	Litt vekt bakover - Ikke så mye	3	6
12	6	70,0	Lene seg bakover	2	7
13	3	80,0	Legge vekt på bakre fot	2	7
14	1	75,0	Lene meg bakover	2	5

No	Improvments	Comments	Observation: Leaning	Observation: Errors	Observation: Turning ability

			forward		(low-high)
1	Balanse fremfor app, men forstår at det er en prototype		2	0	2
2	Motoren sleit litt. Fikk ikke testa balanse som input		3	0	3
3	Litt "ugjevn" kjørerytme		2	0	4
4	Fjern hakking i starten	Kult!	1	0	6
5		:)	1	1	7
6	Vanskelig å bruke telefonen, Dårlig balanse	Gøy!	2	0	1
7	Startfasen og størrelsen på touch-slideren		2	0	6
8	Ugjenv fart, litt stivere		1	0	4
9	Smudere start	Funker bra når man sparker i gang	3	0	5
10	Litt hakkete start	Mye stasj under brettet, redd for å ødelegge	1	1	6
11	Mer smooth start		2	0	6
12	Hakking i starten - skummelt	Kanskje ha "fot avtrykk" på skateboardet for å vise nybegynnere hvordan føttene skal være plassert (Samt hva som er riktig vei!) Tør ikke å bruke det som et "vanlig" skateboard av hensyn for å ødelegge det. Eks. flytte skateboardet rundt 180 grader - Vanlig å gjøre med foten. Dette kunne man ikke gjøre nå da arduino batteriet var i veien.	2	0	4
13	Design (under brettet)	Veldig morsomt!	1	0	7
14	brems		1	0	3

Appendix D Raw data from summative test

This section includes the raw data from the summative test (Also attached as excel file).

	Which prototype?		Skateboarding	Balance Interface					
No	Prototype 1	Prototype 2	Previous Experience	Fun	Intuitive	Easy	Learning	Accuracy	Precise
1	X		1	6	4	6	6	6	4
2	X		1	7	6	6	7	7	7
3		X	4	6	6	4	5	3	5
4	X		1	7	6	5	5	7	7
5		X	2	7	7	6	7	5	6
6	X		2	7	7	6	7	6	5
7	X		2	7	7	5	6	5	6
8	X		2	7	7	6	7	6	6
9		X	7	6	5	5	6	5	3
10	X		1	5	6	5	7	5	6
11	X		2	7	6	5	7	7	7
12	X	X	1	6	6	6	7	6	6
13	X	X	1	7	4	3	5	3	3
14	X	X	1	7	6	6	7	6	7
15	X	X	1	7	6	4	7	5	6
16	X		1	7	7	6	7	7	7
17	X		1	7	6	5	7		6

No	Prototype					Overall	Author comments
	Understanding	Responsiveness	Control	UX	Technical issues	Satisfaction	
1	6	5	5	7	2	6	
2	6	7	5	5	1	7	
3	6	6	5	5	5	5	
4	7	7	6	6	1	7	
5	6	6	6	7	7	6	
6	7	6	6	7	1	7	
7	6	6	5	6	5	6	
8	6	6	7	7	1	7	
9	5	3	5	5	6	4	
10	5	6	5	6	1	5	
11	6	6	7	7	5	5	
12	7	6	7	7	2	6	
13	4	3	5	5	3	5	
14	6	6	7	7	2	7	
15	6	6	6	7	1	6	
16	7	2	6	7	6	7	Participant tested with a partially working interface
17	3	5	4	7		7	2 missing data points. Participant tested with a partially working interface

	Qualitative Questions			
No	Overall impression	Best attributes	Difficulties	Technical challenges
1	Imponerende til protoype å være	At det fungerte	Svinging og akselerasjon	
2				
3	Veldig morsomt	Det største	Kalibreringen var delvis	Kalibrering
4	Veldig morsomt - mye bedre enn et vanlig skateboard som man ikke har kontroll over	- Hele prototypen var bra - Feedback på kroppsbevegelser var veldig intuitivt		
5	Bra!	Det at det kjører av seg selv	Litt mye gass i starten	Motoren stopped ved flere anledninger
6	Veldig morsomt, lett å operere.	Fart og respons	Noe vanslekig å kjøre sakte- Måtte bruke mye vekt for å få toppfart. Litt vanskelig å bremse	
7	Veldig bra med mye potensiale	Automatisk fremdrift	Balansestyringen er bra, men det er rom for forbedring	Til tider vanskelig å oppnå toppfart
8	Utrolig morsomt og overaskende enkelt	Hvor lite energi jeg må bruke	Bremsing var litt hakkete	
9	Gøy, men følte motoren slet litt og kalibreringen ikke ble god nok	Farten	Mer sensitiv bremsing	Motoren rykket og kuttet av
10	Litt treig i begynnelsen, men grei styring når man finner balanser	Styringen var intuitiv Når man kom i gang	Hadde vært veldig bra hvis laggen i begynnelsen ble borte, Jevn akselerasjon	
11	Morsomt konsept, godt gjennomført med lys	Farten	Kalibreringen kunne ha vært raskere	Nei
12	Veldig gøy, kunne lekt mer med den. Likte applikasjonen på mobilen til brettet.	Veldig enkelt og intuitivt	Balansestyringen var kanskje ikke sensitiv nok. Litt vanskelig å bremse med appen.	Opplevde at ene brettet "hang" seg opp, da jeg skulle få den til å starte igjen. Det lagde bare lyd og lyste rødt.
13	Veldig artig! Litt vanskelig å kjøre siden jeg har null erfaring med skateboard og balanse, men var veldig gøy	At den går framover og bakover uten at jeg trenger å bevege beina med unntak av vektskifting. Gøy når man også får til svingene	Svinging var veldig vanskelig, kunne kanskje vært hakket mer sensitivt. Og kanskje bedre bremser, gjorte avstigninga vanskelig. Litt vanskelig å si fort, men kan ha noe med å gjøre med mangel på erfaring.	Vanskelig å svinge og gi gass, og med å registrere vektendringene.
14	Kjempebra, det var skikkelig gøy å kjøre og det ble mye morsommere, underveis.	Likte lysene skikkelig bra og at det kunne gå så kjapt eller så sakte som jeg ville.	Svingingen var vanskelig i starten, men lærte det etter hvert. Men slet litt med å få den til å gå forover i starten.	Når jeg kjørte med appen kom jeg bort til OFF knappen
15	Det var veldig morsomt å teste begge skateboardene, de fungerte bra, måtte bare venne meg til det	At det er en skateboard som kjører selv :)	Av-og-påstigning var nok litt uvant for meg	
16	Meget positivt og veldig kult	Alt, hele konseptet - balansestyring, motor, skateboard, sykt kult.	Ingenting burde vært annerldes	Sensor fremover var det utfordinger med
17	Veldig bra! Har lyst på den!	Designet, fargen på hjulene. Måten man styrer på.	Svinging er vanskelig men jeg tror det går bedre med tiden	Litt sensor-problemer fordi jeg testet helt på slutten.

Appendix E Extra photos

This section includes addition photos of the prototype, the formative test and the summative test

E.1. Prototype photos

Figure 14.13 Close-up of prototype #1

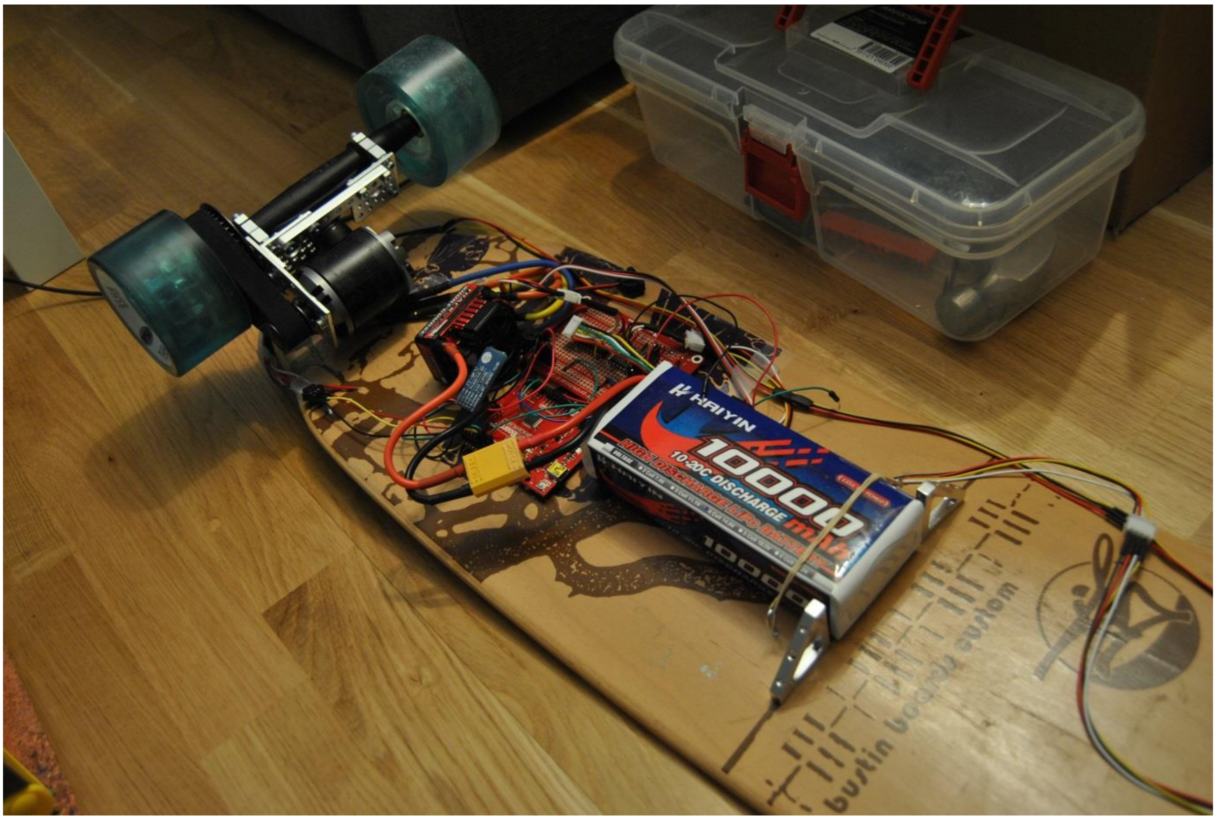

Figure 14.14 Prototype #1 before attaching the enclosure

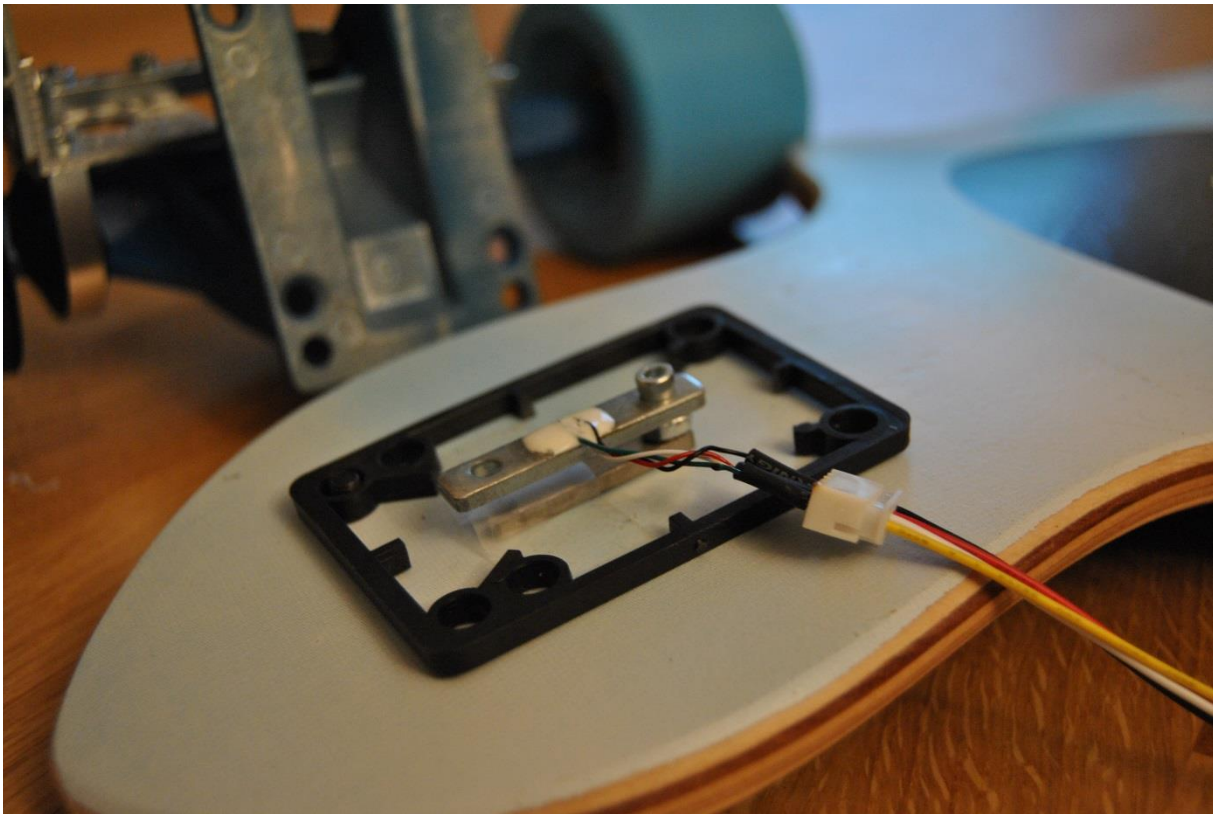

Figure 14.15 The load sensor on prototype #2

Figure 14.16 Prototype #2 drive-train components

E.2. Formative test

Figure 14.17 Participant testing the prototype

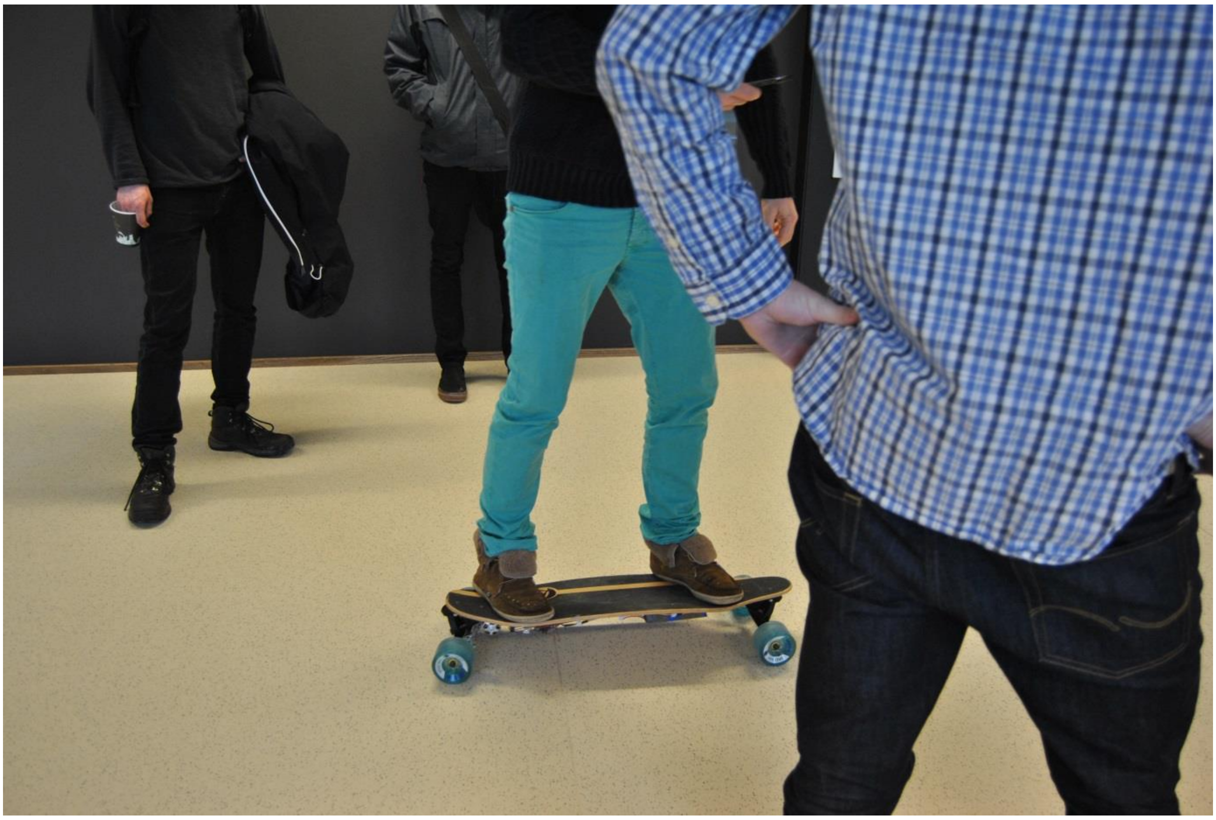

Figure 14.18 Bystanders watching the prototype being tested

Figure 14.19 Close up of the prototype

Figure 14.20 Prototype being tested

E.3. Summative test

Figure 14.21 Prototype #2 has broken down

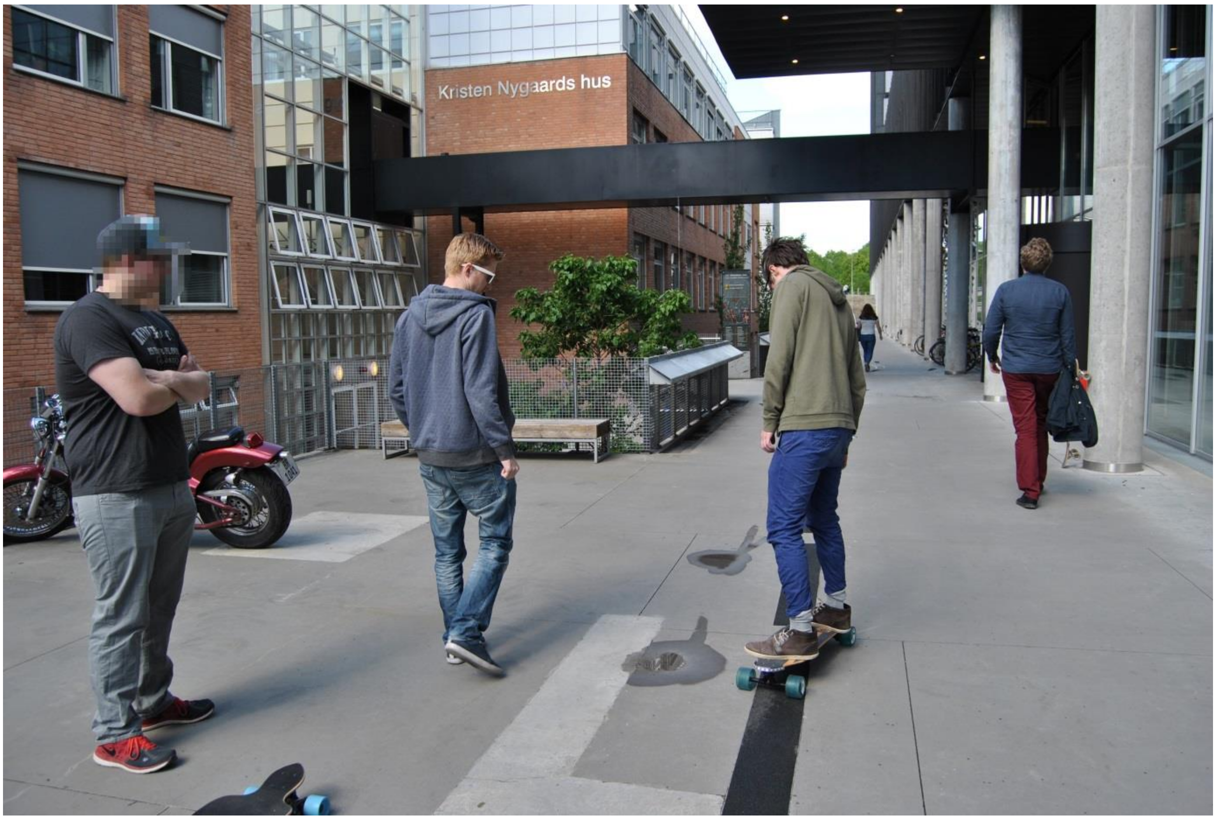

Figure 14.22 Participant accelerating on prototype #1

Figure 14.23 Close-up of Prototype #2

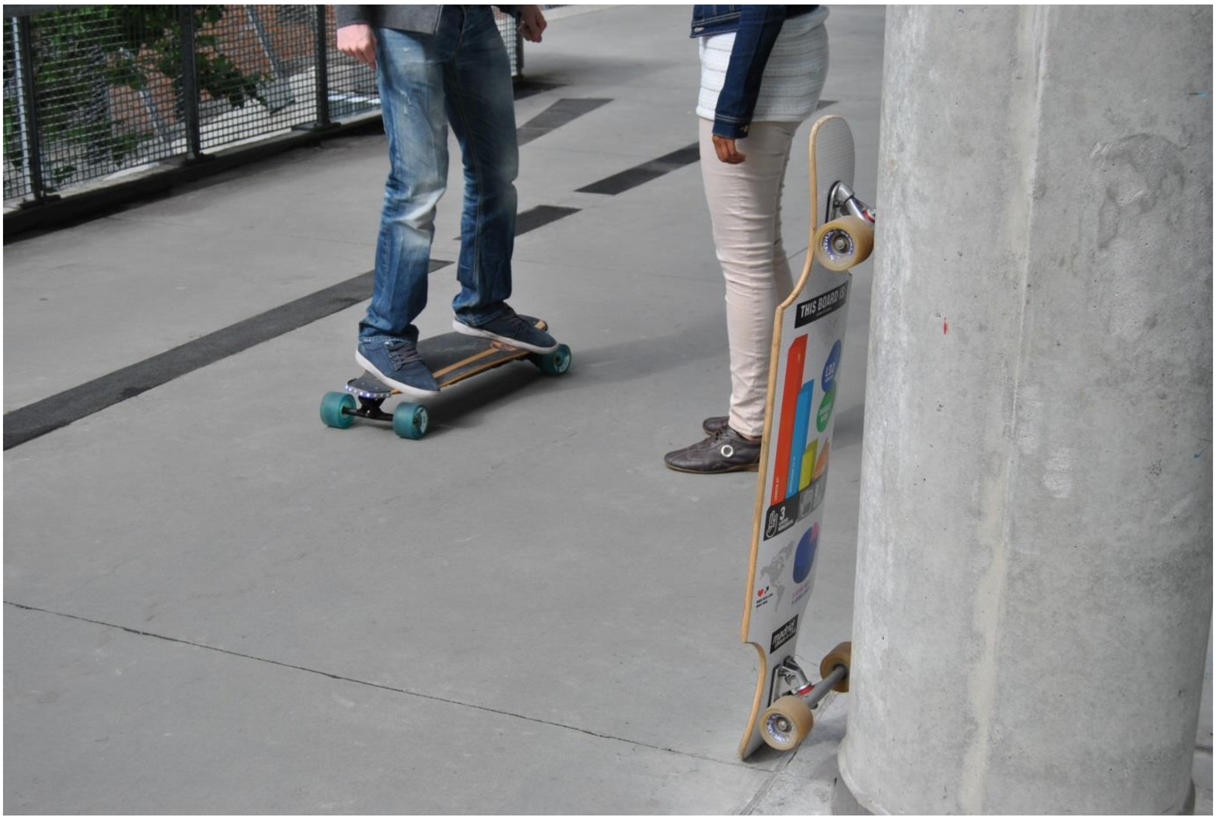

Figure 14.24 Demonstrating how to turn on prototype #1

Figure 14.25 Stepping on prototype #1

Figure 14.26 Prototype #1 being tested

Appendix F Paper

Implications for Design of Personal Mobility Devices with Balance-Based Natural User Interfaces

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Abstract. In this paper, we present a set of guidelines for designing personal mobility devices (PMDs) with body balance exclusively as input modality. Using an online survey, focus group and design workshop, we designed several PMD prototypes that used a natural user interface (NUI) and balance as its only form of user input. Based on these designs we constructed a physical and functional PMD prototype, which was tested using a usability test to explore how the balance interface should be designed. In conclusion, we discuss whether the guidelines from the literature could apply when designing PMDs and present a set of implications for the design of PMDs with balance-based NUIs based on both the guidelines and our own findings.

Keywords: Personal mobility · Embodied interaction · Natural user interface

1 Introduction

In July 2014, personal mobility devices (PMDs), such as self-balancing vehicles, were legalized on public roads by the Norwegian government. With the introduction of PMDs, a new market of cheap, environmentally friendly, and personal transportation vehicles would be available to the public. However, more than two months after the legalization the adoption rate was still very low [1], which suggested that the current vehicles had failed to meet the requirements of the public. This potential need for a redesign was the main motivation for our study on improving PMDs using a Natural User Interface (NUI) interaction approach. As such, we gathered user requirements through an online survey and designed several PMD prototypes using a focus group and design workshop. This was followed by a usability test on one of the designs to identify possible implications for the design of balance-based PMD interfaces.

This paper is structured as follows: We start by presenting related work on balance as input and user experience (UX) of movement-based interfaces, and use this literature to propose a list of design implications for the prototype and its interface. Next, we present the methods used to collect requirements, design and test the prototype using these implications. We then present the results from each of the methods, and finally discuss the proposed implications based on our findings.

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2 Related Work

Within Human-Computer Interaction (HCI), much of the research on balance-based interfaces so far revolves around balance as input in a virtual environment. In a study by Fikkert et al. [2], the authors compared the use of lower-body input to traditional hand held controllers using a Wii Balance Board and Wii Remote. They found that while using the remote to navigate was significantly faster, the balance board was both easier to learn and use and felt more intuitive to the users, and the users strongly indicated that they enjoyed using the balance board more. These results indicated that while a balance-based interface may not be as precise as a traditional button-based interface, it could still be easier to learn and provide a more fun and intuitive user experience.

Wang & Lindeman [3] conducted a study comparing two modes of balance control; isometric and elastic (tilt), with a leaning-based surfboard interface in a 3D virtual environment. The authors found that participants preferred the elastic board because it was more intuitive, realistic, fun and provided a higher level of presence. However, they found no significant difference in user performance, indicating that people prefer elastic balance interfaces over non-elastic, but that this preference has no impact on performance.

Haan et al. [4] demonstrated different scenarios where balance could assist traditional hand-operated input in a virtual reality (VR) setting. They tested the use of a balance interface as an interaction supplement in three different interaction modes (3D rotation, navigation and abstract control), both while sitting and standing. They found that all three modes worked well, but noted that side-to-side motion was slower and required more effort on the user's part in all modes. The authors concluded that the balance board was effective and easy to use, suggesting that the balance could easily be used in a wide variety of applications, even outside of VR.

Research on user experience is often concerned mostly with graphical interfaces and screens, but the rapid development of small integrated processors in the last decade has opened the door for UX research on embedded computers without any graphical or screen-based interface. In a study by Moen [5] the authors present the design process and user explorations of a wearable movement-based interaction concept called the BodyBug. This was created to explore full-body movement, as the interaction modality. Through their observations of users interacting with the BodyBug, they identified that the success of embodied user experience relies on having movement-triggers as well as a social excuse or reason to move, i.e. that these movement patterns are socially and culturally accepted in their context. Additionally, the authors observed large individual differences regarding which movements felt comfortable to the participants, suggesting that enforcing a set of pre-defined gestures or strict rules for a successful interaction may limit the user experience for users that feel uncomfortable with these kinds of body movements.

In a study by Larssen et al. [6] exploring movement-based input using a Sony Playstation2® and Eyetoy™, the authors used two existing frameworks for conceptualizing the interaction: *Sensible, Sensable, Desirable: a Framework for Designing Physical Interfaces* [7] and *Making Sense of Sensing Systems: Five Questions for*

Designers and Researchers [8]. The frameworks were used to categorize the movements of the participants during play, and look at how movement as input would hold as communication in the interaction. The authors found that both frameworks were valuable tools to aid researchers and designers in understanding the specific challenges that new interaction and input options present. They conclude that when movement is the primary means of interaction, the forms of movement, enabled or constrained by the human body together with the affordances of the technology, need to be a primary focus of design. Additionally, an intuitive and natural interaction through movement relies on appropriate mapping between movement and function.

Table 1. Our design guidelines for a PMD with a balance interface based on related work

Guidelines	Related work
1. Elastic interfaces increase user experience over isometric	[3]
2. Leaning from side-to-side requires more effort	[4]
3. A movement based interface relies on movement-triggers and a social excuse to move	[5]
4. There are large individual differences in which movements feel natural	[5]
5. The device must be designed around the forms of movement as allowed by the human body	[6]
6. Intuitive and natural interactions relies on appropriate mapping between movement and function	[6]

2.1 Design Guidelines from Related Work

Based on this literature we have assembled a set of guidelines for the design that we have attempted to incorporate in the design process of the prototype (see Table 1). We will return to these guidelines following our results to evaluate and discuss whether they can be used as design implications for future PMD interfaces.

3 Method

The aim of the study was to identify opportunities for improving PMDs using a NUI and lower-body input approach. We used Blake's definition of NUI *"A natural user interface is a user interface designed to reuse existing skills for interacting appropriately with content."* [9], and focused on designing an interface that: Would reuse existing skills to ease the learning curve, was "invisible" in the sense that it allowed input through direct manipulations of the device without any use of buttons, dials or switches etc. as metaphors, and finally that took advantage of the users' own intuition through tacit knowledge within a given context – in our case, motor skills and balance. In this paper, we present three of the methods used during the study; a survey to gather requirements, a focus group to generate design concepts and a formative usability test conducted before the implementation of the balance interface.

3.1 Survey

We conducted a quantitative online survey (N = 248) with the purpose of identifying user requirements and needs in the prototype. We used the following three PMD product categories as a way of framing the questions around familiar designs: Self-balancing/Segway, e-bike and electric kick-scooter. The users were asked to assess various attributes such as size, weight, safety and speed in order to identify what people like and dislike about each device category. This resulted in a list of good and bad attributes for each category that would lay the foundation for the requirement specification and become the basis for the design of the prototype.

The target group was adult Norwegians with a daily transportation need, and particularly people living in urban areas. The timeframe was set to two months. Participants were mainly recruited using online forums, had a fairly even age distribution (Mean = 37.83, SD = 3.19), but a gender distribution skewed towards males (81 %).

3.2 Focus Group and Design Workshop

To create a set of initial design ideas from the survey results and requirement specification, a focus group was chosen. This is a common method to use in combination with surveys and the pairing of these two methods are one of the leading ways of combining qualitative and quantitative research methods [10]. Additionally, because of the easy access to students with previous HCI experience at our department, it allowed for the collection of multiple perspectives in a group of people who are ordinary users in relation to PMDs, but have years of experience in conducting user-centered design and research. As a result, the focus group was coupled with a design workshop, allowing the participants to create simple paper prototypes from the generated ideas.

The focus group was conducted over approximately 2 h and included 7 participants. All participants were master students associated with the Department of Informatics at the University, and 5 of them were students of the Design, Use, Interaction program with years of experience in fields such as HCI, UCD and UX. The focus group did not have a structured set of questions, but instead used the survey results to fuel the discussion and encourage the participants to discuss if and why they agreed or disagreed with the results, adding a qualitative layer to the survey findings. Following this discussion was a brainstorming stage, where the participants generated ideas based on existing man-powered means of transport. These ideas were then discussed in relation to the survey results, the opinions of the participants, and the balance user interface. The participants formed groups of two or three and created prototypes from the two ideas that were found to be the best match with post-it notes of different colors to represent the added components for motorization; motor, battery, and electronics. Each group then presented their design to the others and explained their thoughts on how the prototype would be controlled. In the weeks following the focus group, the participants were contacted via e-mail to evaluate additional prototype iterations.

3.3 Usability Testing

Drawing on the results from the two previous activities, we continued with the design of a skateboard prototype. The paper prototypes from the workshop were unified and improved though multiple iterations with the help of the participants from the workshop. The resulting prototype was then built as a functional and testable electric skateboard design.

Initial user testing of the design included simulating the balance control with an app on a mobile phone as a formative usability test. The test (N = 14) was conducted inside a long hallway at the department over the course of three days with the purpose of learning how the balance interface should be designed and implemented, as well as getting early feedback on the design. The participants were recruited from the students that were studying in close proximity to the hallway. The prototype gained much attention from bystanders, but many were too afraid to try it themselves and only wanted to watch. The participants were observed while executing a set of basic tasks such as acceleration, maintaining a constant speed, turning and breaking. After the test, they completed a short, one-page form about their thoughts on the design and balance interface. Each test took only about a minute to complete, but many participants wanted to try it for longer. All participants were students at the department (both bachelor and master students), aged between 20 and 31. The simulation of balance was carried out by asking participants to lean forwards to put weight on the front of the board to accelerate. The actual acceleration was accomplished using a slider control on a Bluetooth connected mobile phone controlled by the user.

4 Results

4.1 Results from the Online Survey

Of the 248 respondents, only 15 (6.0 %) reported that they currently own a PMD. The same number of people reported having good prior experience with PMDs, followed by 24.6 % having tried PMDs once or twice, 36.3 % had only seen them in use and 33.1 % had no prior experience. This show that even with few PMD owners, there is a fair share of people who have tried riding a PMD at least once (30.6 %).

There was a significantly higher acceptance for the use of e-bikes than for Segways or electric scooters. Table 2 shows the willingness to use the three vehicles as a daily means of transportation.

Table 2. Distribution of people who could see themselves use a Segway, e-bike or electric scooter daily

PMD	Would use	Would not use	Don't know	Already owns
Segway	13.7 %	78.6 %	7.3 %	0.4 %
E-bike	51.6 %	32.7 %	13.7 %	2.0 %
Electric scooter	19.0 %	69.4 %	10.9 %	0.8 %

Based on the respondents answer in the previous question, they were divided into groups of positive (for answers “would use” and “already owns”) or non-positive (for answers “would not use” and “don’t know”) and asked about which attributes they found the most positive or the most negative for each device type. These questions were not mandatory, so respondents could continue without checking any attributes.

When it comes to the Segway results (Table 3), the participants were particularly unsatisfied with the price, how they are perceived by others, size and weight, and safety. They were most satisfied with ease of use, range and the environmental aspects. Additionally, people who are positive to Segway use, mostly checked the opposite reasons, compared to those asked to list negative attributes. The exception is the ambiguous “Replaces alternative transport” vs. “Prefer alternative transport”, which is frequently cited by both groups (see Table 3). The positive reasons given in “Other” were related to the enjoyment and fun of riding the Segway, while negative reasons were mostly related to health and elaborations on how people are perceived.

Table 3. Positive (left) and negative (right) citied attributes of the Segway

Most positive Segway attributes		Most negative Segway attributes	
Ease of use	60.0 %	Price	68.1 %
Replaces alternative transport	57.1 %	How I’m perceived	44.6 %
Range	28.6 %	Prefer alternative transport	38.5 %
Environmental	22.9 %	Size and weight	28.2 %
Speed	20.0 %	Safety	23.9 %
Size and weight	17.1 %	Other	22.5 %
How I’m perceived	14.3 %	Speed	10.3 %
Other	11.4 %	Range	8.0 %
Safety	2.9 %	Ease of use	4.2 %
Price	0.0 %	Environmental	2.8 %

Interestingly, all positive attributes were cited more frequently with the e-bike compared to the Segway, and almost all the negative attributes were cited less frequently. Beyond this, the most notable differences were that “how I’m perceived” was

Table 4. Positive (left) and negative (right) citied attributes of the e-bike

Most positive e-bike attributes		Most negative e-bike attributes	
Replaces alternative transport	70.7 %	Prefer alternative transport	40.9 %
Ease of use	69.9 %	Price	34.8 %
Range	56.4 %	Other	33.0 %
Speed	47.4 %	How I’m perceived	16.5 %
Environmental	41.4 %	Size and weight	15.7 %
Price	28.6 %	Speed	5.2 %
Size and weight	21.1 %	Safety	4.3 %
How I’m perceived	17.3 %	Range	3.5 %
Safety	13.5 %	Environmental	2.6 %
Other	12.0 %	Ease of use	1.7 %

much more rarely cited as a negative attribute, and that “range”, “speed”, “environmental”, and “price” were cited much more frequently as positive e-bike attributes. The full list of e-bike results can be found in Table 4.

When it comes to electric scooters (Table 5), the results show that “size and weight”, “ease of use” and “price” were rated the most positively while, “prefer alternative transport”, “how I’m perceived” and “safety” were the most negative.

Table 5. Positive (left) and negative (right) citied attributes of the electric scooter

Most positive electric scooter attributes		Most negative electric scooter attributes	
Size and weight	63.3 %	Prefer alternative transport	41.2 %
Ease of use	53.1 %	How I’m perceived	36.2 %
Price	46.9 %	Safety	28.6 %
Replaces alternative transport	38.8 %	Other	19.6 %
Speed	28.6 %	Price	17.6 %
How I’m perceived	20.4 %	Range	13.6 %
Environmental	20.4 %	Size and weight	9.5 %
Other	16.3 %	Ease of use	8.0 %
Range	6.1 %	Speed	5.5 %
Safety	4.1 %	Environmental	0.0 %

4.2 Focus Group and Design Workshop Results

Only one of the participants had personal experience riding a PMD (during a Segway sightseeing tour), but all others were familiar with the concept. In general, all participants were in agreement with the main findings of the survey, stating that the e-bike was the most useful of the three because it operates and looks like a normal bike, and because it doesn’t stand out as much as devices with an unique look. One participant said: “The only one I’d use personally would be the e-bike. The Segway looks like it’s for obese or lazy people.” They also found the e-bike to be the safest option of the three and liked that it can be used even with a depleted battery. “If the battery runs out on a Segway, I’m basically stuck, but if it runs out on an e-bike, it turns into a normal bike”. The participants found the Segway category to be clumsy and impractical mostly because of its large size and weight, making it difficult to transport or use in combination with public transit systems, as well as difficulties related to parking. One participant asked, “What am I going to do with it when I go to buy groceries? It’s too big to go inside the store, right?” The participants all found the Segway to be better suited in specialized tasks and used for in-doors transport of large buildings like airports, shopping malls, hospitals and schools, and agreed that it “looks way too silly” for normal urban transportation. Regarding electric kick-scooters, the participants were less vocal, but expressed concerns regarding the safety and stability of the vehicle at high speeds. “Is it really stable at high speeds? I don’t think I would feel comfortable going 20 km/h on a kick-scooter.” Otherwise, they agreed with the results, that the smaller size and weight was a plus, but that an e-bike or normal bike is still a better choice in most situations. They also noted that PMDs in general would probably benefit substantially from better facilitation in the cities, like more dedicated bike roads.

The brainstorming stage resulted in a long list of ideas such as electric skateboards or longboards, rollerblades, roller skis, snow racers, snake boards and more. Out of this list, the participants found the skateboard/longboard and rollerblades concepts to be the best fit for the requirements and chose to continue with these in the paper prototyping stage. The participants formed groups and discussed the optimal location of the various components, represented using post-it notes, as they created the paper prototypes (see Fig. 1). The participants discussed various design concerns as they made decisions, such as initiatives to hide the components as much as possible, keeping the device lightweight and distributing the weight equally on the front and back of the vehicle. Some of the groups also made minor alterations to their designs when they saw what the others had created (Fig. 2).

Fig. 1. Pictures from the focus group (left) and design workshop (right)

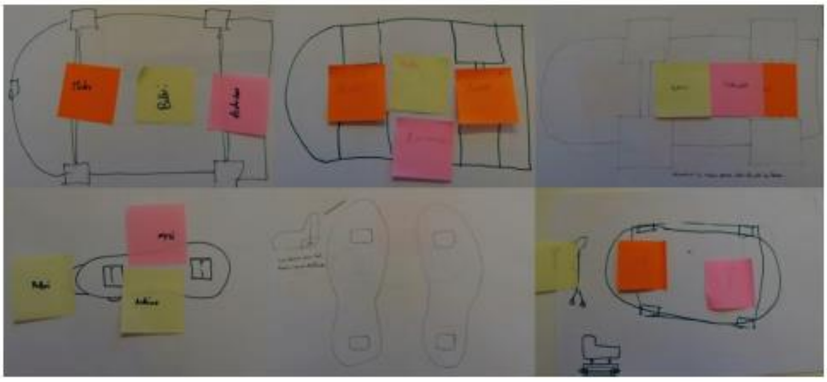

Fig. 2. Paper prototypes of the skateboard (top row) and roller blades (bottom row). Post-it note colors: Orange = motor, yellow = battery, pink = electronics (Color figure online).

4.3 Results from the Usability Test

In spite of several technical difficulties with the prototype during testing, virtually everyone who tried expressed how much fun it was to ride. The participants had mixed previous experience with skateboards and longboards (see Table 6), and those with little experience in particular had difficulties with keeping their balance and turning during their first few seconds on the board. However, they learned quickly and after only a minute you could see a noticeable difference, which was visible as they kept a straighter and more confident posture, showed improved turning ability and willingly increased the driving speed. Several of the participants wanted, on their own initiative, to ride the board back to the starting point after completing the test. Many of the participants also kept riding for longer than necessary, and some actually came back for more after a few minutes because they wanted to try again.

Table 6. Ratings of various attributes from the user test

Rating from 1 (very low) to 7 (very high)	Mean	Median	SD
Previous skateboard/longboard experience	3.29	3	1.94
Overall prototype satisfaction	6.14	6	0.84
Observed amount of leaning forwards and backwards	1.71	2	0.73
Observed ability to turn left and right	4.57	4.5	1.87

During the simulation, the participants were asked to lean forwards on the board to accelerate as if it was their body weight distribution that controlled the speed of the board. The amount of visible lean did not vary substantially between the participants (see Table 6). Some participants hardly showed any visible lean at all, and others leaned only a little bit. Thus, we did not witness large individual differences. The amount of lean on toes and heels (to turn the board) varied slightly more, but could have been related to the participants' previous board experience. Those with more experience leaned from side to side more visibly than those with less experience (Fig. 3).

Fig. 3. Participants standing on the prototype board

Next, the participants were asked how they would prefer the device to tilt elastically as they shifted their balance, between the choices: side-to-side (turning), front-to-back (accelerating/breaking), both or neither. 78.6 % of the participants said they wanted side-to-side tilt only, i.e. elastic when turning and isometric when accelerating and breaking, similar to a traditional longboard. Further, we asked how much weight should be applied on the front of the board before the vehicle starts accelerating. All participants gave values in a range between 60 % and 80 % of body weight (mean = 67.59, SD = 7.76). Finally we asked for suggestions on design improvements, and with the exception of two participants that called for balance as input rather than a simulation, all suggestions were related to various technical issues, mostly motor stuttering at slow speeds due to the use of an underpowered motor in the prototype (Fig. 4).

Fig. 4. Participants riding the prototype board during usability test

4.4 Design Implications

Revising our list of guidelines based on the results from the study, we present a list of design implications for PMDs using balance as input. We summarize these implications in Table 7. Most of the guidelines showed to be useful when designing a balance-based PMD interface. However, implication #1 was found only to be partially true while for implication #2 and #4, our results were inconclusive and further research is required.

Table 7. Design implications for balance-based PMD interfaces

Implications	PMD applicable
1. Elastic interfaces increase user experience over isometric	Partially
2. Leaning from side-to-side requires more effort	Unconfirmed
3. A movement based interface relies on movement-triggers and a social excuse to move	Yes
4. There are large individual differences in which movements feel natural	Unconfirmed
5. The device must be designed around the forms of movement as allowed by the human body	Yes
6. Intuitive and natural interactions relies on appropriate mapping between movement and function	Yes
7. Familiarity increases design acceptance	New
8. The interface should encourage visible body-movements	New

5 Discussion

As we have only simulated balance control, it is too early to draw any conclusions on the usability of the interface itself. Instead, we will evaluate the guidelines according to how well we found them to apply for the design of balance-based PMDs based on our results. When it comes to elastic vs. isometric interfaces (Table 7, implication #1), we found that for this form factor, maintaining the traditional skateboard design with elastic sides for turning and isometric front and back for accelerating and breaking was preferred by the vast majority of the participants. This could indicate that designing for familiarity in an interface is valued more than the added feedback gained from elasticity, and that a traditional skateboard design is preferred over a board with an elastic front and back, such as a self-balancing skateboard. However, this is not necessarily the case with other form factors. Similarly, we observed a lower amount of leaning on each foot (on the front and back of the board) compared to leaning on toes and heels to turn, which could indicate that side-to-side movement requires more effort (implication #2). On the other hand, it is certainly possible that this is simply a result of the participants knowing that any leaning on the front and back foot did not actually produce an effect during simulation. Furthermore, visible leaning is not required for changing ones distribution of balance between the feet, so this should be tested more thoroughly with a fully implemented balance interface.

As our design used an existing vehicle as a base and was kept as close to its original design as possible, users are given the same socio-cultural excuse to move while interacting with it as people riding traditional longboards (implication #3). Longboard riders certainly move while traveling, so these movement-triggers will transfer over to riders of electric boards. We witnessed only small individual differences in movements during the test, so we were unable to verify this implication (implication #4). There could be multiple reasons for this. First, operation of the board did not necessarily encourage large movements, thus it is expected to only see small movements being made by the participants. Had the design encouraged larger movements, the differences between participants may have been more noticeable when some of them were uncomfortable with performing large movements. Additionally, it is probable that people will be performing larger movements as they become more comfortable with the device. The participants only tested the vehicle for a few minutes, and most of them did not have extensive experience with a skateboard or longboard.

The proposed interface is designed to accelerate when the user leans on the front foot. We argue that this interaction is both appropriate and natural (implication #5 and #6) because it is what humans do instinctively to keep their balance when standing on an accelerating platform, thus the movement of the vehicle and user are working together to keep the user balanced and on the board. The opposite (leaning back to accelerate) would likely make the user lose their balance as the accelerating platform and the users balance would both contribute towards pushing the user off the board. Because of this, we consider both implications relevant for designing PMD interfaces.

Adding to the guidelines, we found it necessary to introduce a few additional design implications not covered in the literature. Both in the survey and focus group we found that the acceptance of a PMD would greatly increase if the design and interface was familiar (implication #7). Most people seem to be quite self-conscious when riding a PMD and they prefer to use vehicles that “blend in” in the urban landscape. We also found that devices where the rider has a static posture were perceived very negatively (implication #8). We would therefore encourage designers of future PMDs to take this into consideration and design interfaces that encourage some form of body movement. Whether this stems from a need for improved health or mere esthetics remains a question.

6 Conclusion

In this paper, we have presented a set of guidelines based on related work for the design of balance-based PMD interfaces. Using a survey, focus group, design workshop and usability test, we designed and tested a PMD prototype to evaluate our guidelines. Based on our results, we have verified and extended the guidelines to a list of design implications for PMDs with balance-based user interfaces. We found that most of the guidelines were applicable in our context. Additionally, we found that design and interface familiarity is essential for the acceptance and willingness to use a PMD, and that the interface should encourage visible body-movements in the interaction. As we have only simulated the interface in our tests, future work should further investigate these implications with a fully implemented balance interface.

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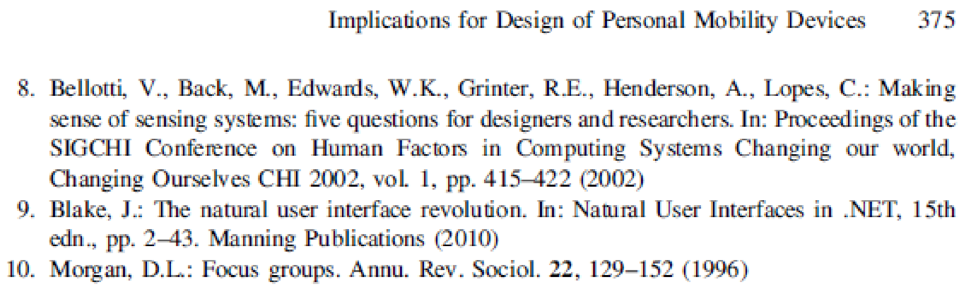

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