smart insoles

Prevention of Falls in Older People through Instant Risk Analysis and Signalling

Master Thesis by Rosan Foppen
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TU Delft
Faculty of Industrial Engineering
M.Sc. Design for Interaction

Colophon

This is the final documentation of my graduation project titled *'Prevention of falls in older people through instant risk analysis and signalling'*.

Executed as a research project for the Faculty of Industrial Design Engineering in Delft, this project completes my Master's program Design for Interaction.

Rosan Foppen

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Master Thesis
M.Sc. Design for Interaction
Faculty of Industrial Design Engineering Delft
University of Technology

Supervisory Team

Chair
Jellema, A.H., MSc
Department of Human-Centered Design
Section of Applied Ergonomics and Design
Mentor
Dr. Song, Y. (Wolf)
Department of Sustainable Design Engineering
Section of Materials and Manufacturing
Mentor
Prof. Dr. van der Cammen, T.J.M. Department of Human-Centered Design Section of Applied Ergonomics and Design

Delft University of Technology

Faculty of Industrial Design Engineering
Landbergstraat 15
2628 CE Delft
The Netherlands

Executive Summary

Falls in the elderly are a leading cause of injury, affecting one in three older adults annually. These fall incidents can lead to various disabling conditions, and therefore have the ability to affect one's quality of life and independence. Not only are falls potentially taxing to the individual, they are also responsible for a big portion of annual health care costs. Due to an ageing society, the number of falls and their consequences will grow in parallel with the expanding number of seniors, becoming an even greater concern for the health care system. Therefore, there is an ever-increasing need to develop (cost-)effective fall prediction systems to reduce these financial and physical burdens associated with the consequences of a fall.

Many falls occur in the context of walking due to age-related decline in locomotor control. To gain a better understanding of the variations in gait that could foreshadow a fall, an extensive literature search was conducted. Through a study on the characteristic differences in the spatio-temporal parameters that express gait between elderly fallers and non-fallers, the minimum toe clearance parameter (MTC) stood out. This understudied gait variable depicts the minimum vertical distance between the foot of the swing leg and the walking surface. A low MTC resulting from a loss of muscle strength, among other things, increases the probability of unanticipated foot-ground contact. Hence, it is directly linked to the event of a trip, the predominant cause of falls during walking.

Through shifting the MTC height to a safer margin and reducing MTC variability, the risk of a trip can be reduced for the elderly population. Hence, the aim of this project was to design smart insole, focused on falls prevention through the analysis of the MTC parameter. Through transferring impending risk therein to the wearer as a warning signal (termed an intervention), he or she can respond and adapt to avoid a possible fall.

A study into wearable devices aiding fall prevention showed that the majority is targeted at health professionals, enabling them to improve their geriatric research. Though, as the aim of the smart insole is to aid the elderly's lifestyle, the product must be personalized for their needs, capabilities and preferences. Hence, a user-centered approach was applied through including a subset of the elderly population in the design process.

Insights from creative sessions showed that remaining autonomous, mobile, and independent is essential for the elderly. It was also found that the elderly do not resist the use of equipment or technology in order to stay this way. However, the desirable aid must present itself discreetly, as the elderly indicate that they do not want to be stigmatized. These user needs lead to the requirement of the product to be as unobtrusive as possible.

It was also found that the elderly could fall distinctly into active and inactive groups. Similarly, half of the participants want the product to solely motivate them to optimize their gait patterns, while the other half shows interest in additional features, such as additional (balance) exercises and a walking schedule.

Through conducting interviews with healthcare professionals it was found that an intervention targeting the MTC is not enough. In line with the needs from the active elderly, the focus should be supported with concrete advice on sufficient and safe exercise to improve the MTC variable. Personalized feedback is crucial in order for the elderly to gain knowledge on how to limit the occurrence of the intervention, and hence, the possibility of a trip and fall.

Additionally, in order to avoid a false sense of security, the feedback on one's mobility pattern cover all aspects of fall prevention. Solely picking out the MTC element will not prevent falls, therefore, preferably all elements that matter to falls prevention and mobility issues must be incorporated in the design of the smart system enabling fall-risk prediction. Hence, the sensing technology in the smart system must facilitate this.

Through researching theories of persuasive design and user adaptation, it was found that the elderly need to remain motivated in the behavioural change of optimizing their MTC status and overall mobility pattern, to achieve a sustainable long-term effect. Through a properly designed trigger (the intervention or primary signal) and correctly-timed moments of feedback and stimulation (signalled through the application), the elderly user can stay dedicated to change.

As the intervention, or warning signal, targets one of the human senses, research was conducted in the five ways the human body receives sensory information. Generally, four of the five senses significantly diminish with age, except for touch. Finally, also considering the user requirement of a subtle and unobtrusive device, it is decided that the product's warning signal should appeal to the touch. Hence, through ensuring a reliable and discreet intervention, the smart insole is equipped with a touch (haptic) feedback.

After establishing the shape of the intervention, the subsequent focus is the placement of the haptic feedback. Through hosting a creative session together with the focus group participants, as well as peer students, two final options came forward: the top of the wrist and the arch medial of the foot.

In order to ascertain the optimal placement of the intervention, an experiment was conducted to test its effect when located on both the wrist and the foot. In this study, six young adults wore the intervention on the foot or the wrist (3 for both locations) while walking on a treadmill. Vibrations were administered, and its effect on the MTC and stride length parameters was analysed. When placed on the foot, the effect of the intervention was statistically significant for all administered vibrations, and showed no significant side effects affecting other parameters of gait.

It was established that the foot placement had multiple superior functional and aesthetic characteristics, as superior desirability through level of comfort, unobtrusiveness and usability e.g. Therefore, when compared to the wrist placement, the foot placement is preferable both in terms of aesthetic qualities, and the functional qualities. The results from the experiments are therefore conclusive, indicating that the foot is the optimal placement for the device.

With the optimal placement determined, the vibration motor, which transfers the signal, can be integrated in the smart insole. Hence, all technology necessary to monitor the user's gait and convey the signal of a possible impending trip is embedded in the smart insole, positively affecting the ease of use.
Insights gained from the expert interviews concluded that a stand-alone warning signal, such as the haptic intervention, is not sufficient on its own. The alert should be supported by a mobile application. Statistics and feedback concerning past interventions and individual progress, as well information regarding other gait parameters, is crucial. This all should be displayed in a simple and structured manner to provide the user with the necessary and concrete feedback, to thereby ensuring their walking behaviour is adjusted accordingly and sustainably.

Additional field- and research explorations on the necessary content, notification styles, and UI guidelines lead to a product experience map containing a checklist of required UI components for the app, named 'StApp'. Subsequently, with the StApp, a design is proposed of how the app could accompany and support the smart insoles' function.

In this graduation project, an insole with an integrated fall prediction smart system is presented, capturing the physiological risk factor of an impaired MTC variable, and aiding falls prevention in the elderly. The final product consists of three segments in two separate products: detect, warn, and inform. (Detect) Smart insoles that analyse and monitor the user's gait in real-time, in particular the MTC parameter, through a smart system integrated in the sole. (Warn) When an apparent risk is present , the user is alerted through a technological intervention, in the form of vibrational stimulus embedded in the support arch of the insole. (Inform) For the sensor data to be meaningful to the user, an accessory mobile application monitoring multiple gait parameters presents concrete information and advice on sufficient and safe exercise to improve the user's MTC and overall gait.

Finally, healthcare professionals who might be interested in giving more personalized advice to their patients will benefit from the design of the smart insole and accessory StApp, presented in this project. The wearable technology depicted enables optimization of elderly care.

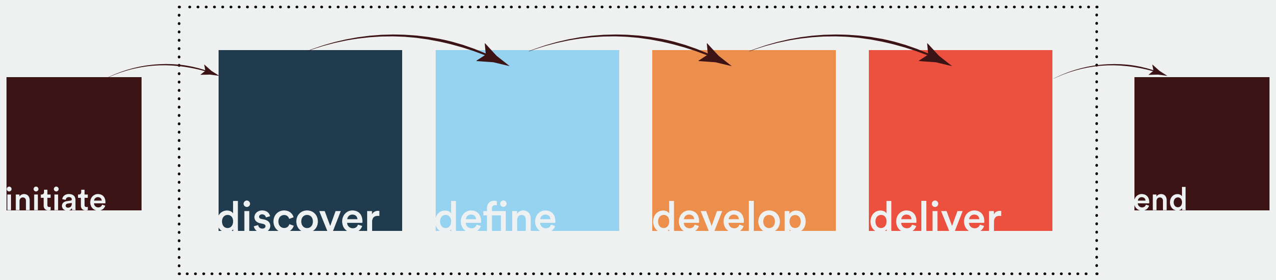
This report concludes with recommendations and conclusions. Smart insoles targeting fall prevention is an interim solution until more research is conducted in the exact capabilities of the smart system. The health professionals indicated that it has been rather difficult to provide every individual with tailor-made consultation. Namely, analysing whether an individual will fall at a specific moment is a complex process and requires the analysis of more variables and variable combinations that this study has not allowed for. However, as the understudied MTC variable is highly linked to the risk of a trip, the shifted focus might open up new possibilities.

More (experimental) research is needed for the development of the smart insoles and the mobile application. Extensive testing is necessary to determine and identify the true and complete effects of an intervention on the elderly's gait patterns, as presented in this graduation thesis. This should verify the lack of any undesirable and troubling side effects, paving the way to towards a smart insole design empowering the elderly user in their independence.

Reading guide

A. Colours represent design phases

Various colours represent each phase of the Double Diamond design process model, together shaping this research/design project.



B. Key insights and message

Chapter 1-3 are summarized with key insights and in what way it contributes towards the design goal.

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0 initiate

Introduction

This introductory chapter introduces the project, through the research topic and the design goal. Subsequently, the approach used to tackle this project is explained, supported by a visual overview.

In this chapter:

0.1 The project brief
0.2 The assignment
0.3 The approach

0.1 The assignment

Falls are a leading cause of injury among the elderly population, affecting one in three adults over the age of 65 annually, and 50% of adults over the age of 80 (Ambrose et al., 2013). Twenty to thirty percent of these individuals will suffer moderate to severe injuries interfering with their ability to continue living in the community, require hospitalization and have an increased risk of death. This has a great impact on their self-sufficiency and quality of life (Ferretti et al., 2013). Every 5 minutes, an elderly person is admitted to the Emergency Department in the Netherlands, due to an unfortunate fall, and up to 13 older adults die daily, due to the consequences of a fall (CBS, 2018). Falls and their consequences are responsible for a big part of health care costs; therefore it is a significant public health issue. In view of the ageing population, these expenditures and numbers of falls are only expected to increase. A prognosis for 2050 is that falls in the older population (65+) will increase with (VeiligheidNL, 2018).

For this project, and in order to provide a solution to this problem, I will focus on designing a smart shoe. This will be realized by providing everyday shoes with a built-in signalling system of fall risk. The user's mobility will be assessed through analysing the obtained data from tthis system, (hopefully) making it possible to identify, and thereafter, predict unsafe situations. Consequently, falls could be prevented through outputting this data to an accessory wearable or other tool/means, which will signal to/alert the user in an easy to interpret and non-intrusive manner.

Identifying at-risk elderly people is the first and most important part of falls prevention management, as applying preventive measures in this vulnerable segment of the population can have a substantial effect (Al-Ama T., 2011). Daily activity greatly reflects the health status of an individual, therefore, movement tracking and analysing one's gait (patterns) is one way to identify the at-risk individuals (Moufawad El Achkar C., 2016). Once identifying and, consequently, predicting risk is achieved in this project, the next action is to design the means/tool to signal the foreseen danger to the user. Researching the best way to do so is of great importance, as the aged population asks for specific design criteria. However, wearable activity monitoring has been gaining momentum in (daily) health assessment; there have been great advances in wearable and sensor technologies which have improved the prospects of these service systems for assisting the elderly (Wang et al., 2017).

Therefore, the aim and challenge of this project is to find out in what way real-time activity monitoring through a wearable (instrumented shoe) can contribute to preventing falls in the elderly population (60+), through instant risk analysis and intervention.

For this project, and in order to provide a solution to the problem of falls among elderly, I will focus on finding a way of making their everyday-shoes 'smart'. This will be realized by providing the shoes with built-in sensors. The user's mobility will be assessed through analysing the obtained data from these sensors, (hopefully) making it possible to identify, and thereafter, predict high-risk situations. Consequently, falls could be prevented through outputting this data to an accessory wearable or other tool/means, which will alert the user of the anticipated risk in an easy to interpret and non-intrusive manner.

Design of a smart shoe concept for elderly people (60+) that aids falls prevention, using real-time activity monitoring and instant risk analysis.

0.2 The approach

A visual overview of how this report is structured is presented in Figure 0.1. The research starts with an introduction on the context of falls in the elderly and the human gait. This background analysis elaborates on topics like fall-risk factors and common age-related changes in gait. Subsequently, to research the (exact) variations in gait that could potentially lead to a fall, a literature study was conducted.

After obtaining a focus on the MTC parameter, immersive pilot tests were conducted to validate the software tool Tracker, allowing for its use in future studies. Ideation- and field explorations are conducted into the elderly's needs and wants, through a user-centered approach with the target group. Expert knowledge derived from interviews enriches this pool of information. Lastly, theories of persuasive design and user adaptation are researched, in order to understand the requirements of a product aimed at behavioural change.

The insights gained in this first phase was funnelled into manageable information, i.e. with the use of a problem definition, context scenarios and stakeholder needs. The second phase concluded with an answer to the problem definition, the design goal, and accessory interaction visions and lists of requirements.

Phase three entails a more focused research and experimental test setup, leading towards a proposal of the final interim solution of the smart insoles with accessory mobile application. Future necessary work, in order to optimize the design of the smart insoles, is presented in Phase four.

Hence, the report is divided into 4 phases and 8 chapters, each chapter opening with an overview page and an introduction to the chapter. At the end, Chapters 1-3 are summarized by key insights and in what way these will contribute to the design goal.

The main research method used throughout this report is the basic design cycle, in a triple diamond set-up (Van Boeijen, 2019). This is a method with continuous switching between design, analysis and synthesis, a circular process. However, for the sake of clarity, the approach is illustrated as linear, see Figure 0.1.

Figure 0.1: Visual overview of how this graduation report is structured.

chapter 1

Background Analysis

This first chapter presents background information on the various topics crucial to understanding the thesis project's scope. The different aspects of the topic of falls in the elderly are researched, followed by an analysis of the human gait.

In this chapter:

1.1 Falls in the elderly
1.2 The human gait
1.3 Key insights and message

1.1 Falls in the elderly

This thesis focuses on the topic of falls in older people and a new strategy to prevent such accidents from happening. To be able to achieve this, the project starts with background research to identify interesting topics, viewpoints and knowledge gaps concerning the intricate problem of falls in the elderly including the major risk factors and existing strategies for falls prevention.

1.1.1 Definition

In 1987, the Kellogg International Working Group on the prevention of falls in the elderly defined a fall as follows:

> "A fall is the unintentionally coming to the ground or some lower level and other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure." (Kellogg, 1987)

Some researchers have used somewhat broader definitions of falls to include those that occur as a result of dizziness and cardiac arrhythmias, for instance, being more appropriate for studies that also address cardiovascular causes of falls. However, since this project will be revolving around falls prevention through mobility assessment, the focus will be on (the identifying factors that impair) sensorimotor function and balance control, for which the Kellogg definition is suitable.

1.1.2 A serious public health issue

Falls are a leading cause of injury among older adults, affecting one in three over the age of 65 and 50% of adults over the age of 80 annually (Ambrose et al., 2013). Twenty to thirty percent of these individuals will suffer moderate to severe injuries, which can subsequently lead to extensive hospital stays. This interferes with their ability to continue living in the community, which by all means has a great impact on their self-sufficiency and, consequently, their quality of life (Ferretti et al., 2013). Therefore, a fall can badly affect and change a person's life, speeding up the normal ageing process.

Approximately one third of older people (65+) living in the community fall at least once a year, with many experiencing multiple falls. Fall incidents in older people are therefore quite common and can lead to various disabling conditions, hospital stays and at worst, death.

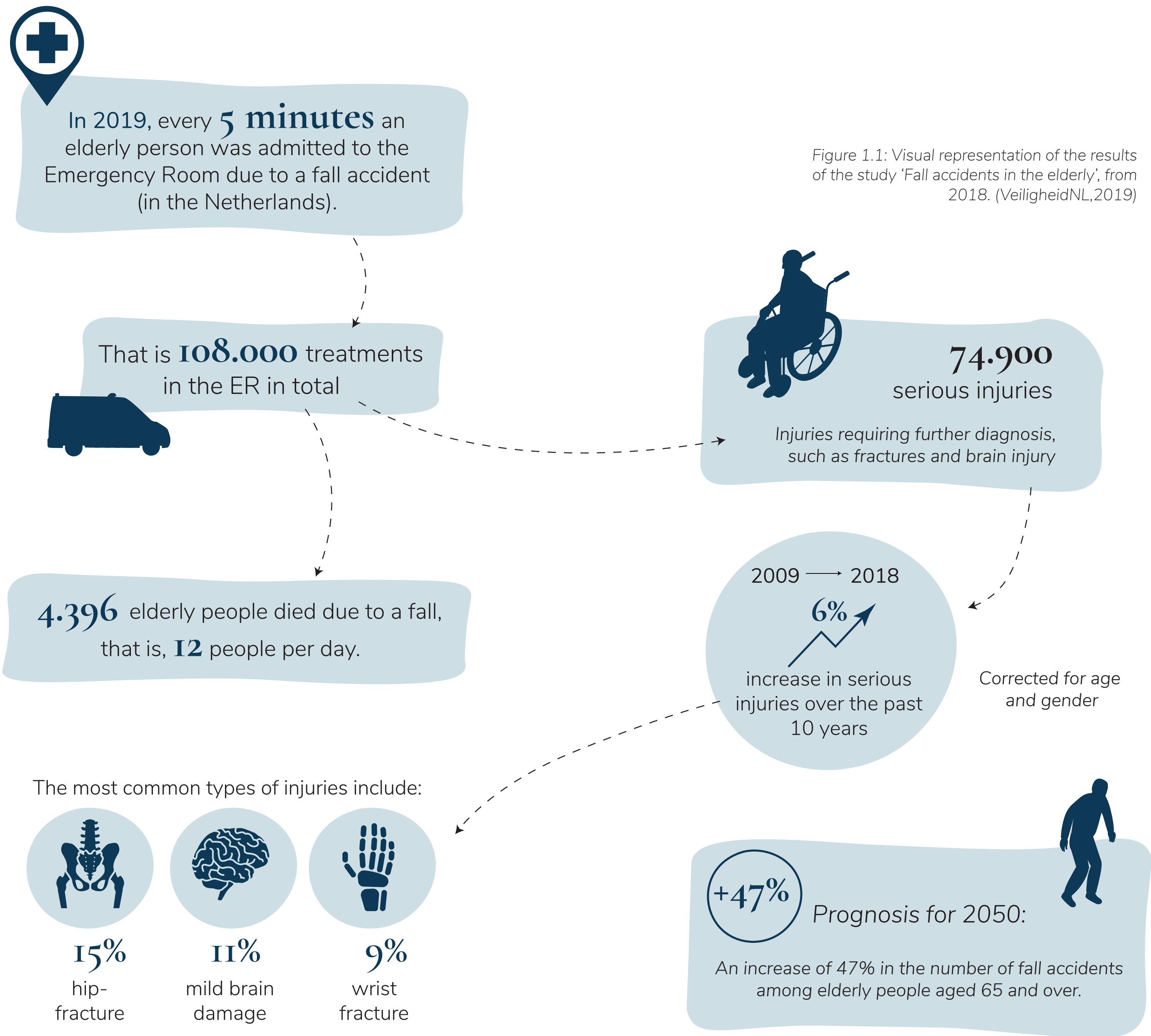


Figure 1.1: Visual representation of the results of the study 'Fall accidents in the elderly', from 2018. (VeiligheidNL,2019)

Every 5 minutes an elderly person is admitted to the Emergency Department in the Netherlands, due to an unfortunate fall, and up to 13 older adults die daily (VeiligheidNL, 2018), see Figure 1.1. Therefore, it is not at all surprising that falls and their consequences are responsible for a big part of health care costs which might be preventable ((Ambrose et al., 2013).

Fall-related costs include direct (medical) costs, consisting of doctor visits, hospital and nursing home care, rehabilitation stays, diagnostic tests, medications and home modifications or assistive devices, for example. Additionally, the indirect costs consist of patient morbidity. Literature on the exact total costs of falls is scarce since there are many difficulties and limitations involved in estimating the economic cost of any disease or condition. However, a calculation was done by VeiligheidNL (2018), suggesting that the direct medical costs for treating injuries as a result from falls in that year alone were approximately €960 million for the elderly aged 65 and over. Moreover, falls roughly account for 70% of all injury-related costs in the elderly population (Day et al., 2001).

The number of falls in the elderly aged 65 and over has been rising for decades. This is due to an increase in the number of elderly people in society, but also by a rise in the incidence of fall accidents in this group. This number is increasing, among other things, because the elderly live at home longer, the place where half of the falls take place for people aged 70+ (WHO, 2007).

Hence, the matter of falls in the elderly is a significant public health issue. In view of the ageing population, these expenditures and numbers of falls are only expected to go up. A prognosis for 2050 is that falls will have a 47% increase among the elderly population (WHO, 2007).

1.1.3 Risk factors

The cause of falling is often multifactorial, resulting from a combination of two or more intrinsic, pharmacological, environmental, behavioural or activity-related factors. Moreover, there are currently over 400 known risk factors for falls (Masud et al., 2001). Knowledge regarding how exactly these factors coincide to lead to a fall remains inadequate. To gain a better understanding of these determinants of falls, the most common division in risk factors in the literature will be presented in this subchapter: intrinsic and extrinsic risk factors, see Figure 1.2.

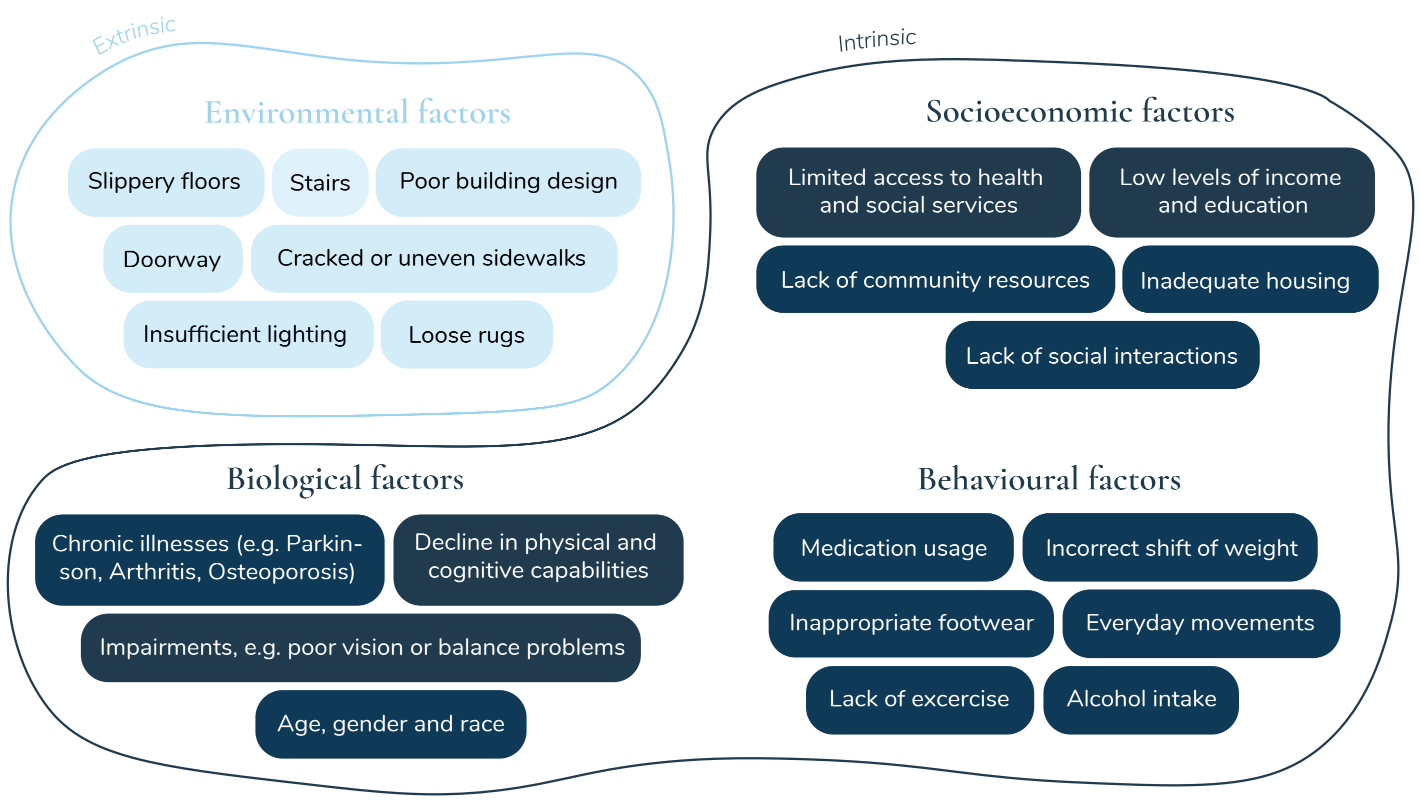
Extrinsic (environmental) risk factors

Extrinsic or environmental factors are those generally considered to include all influences external to a person, including home hazards and hazardous features in the public environment. As these environmental features in and of itself do not pose a threat to a person, the extrinsic factors indicate the interplay of an individuals' physical condition and their environment.

Intrinsic risk factors

Intrinsic factors are related to the person him/herself, traits that are characteristic to a person rather than being determined by that person's environment. According to the World Health Organization (2007), intrinsic fall risk factors can be subdivided into three different groups: biological, behavioural and socioeconomic factors.

Figure 1.2: Risk factor model for falls in older age (WHO, 2007) (PHAC, 2005).



Focus

While knowledge of the environment is known to play a role in minimizing the effect of intrinsic factors on instability, these extrinsic factors cannot generally be controlled, tested or accounted for in clinical assessment. Intrinsic factors on the other hand, cannot only be quantified, but have also consistently been identified as major risk factors for falling (Tinetti, 1986) .

As this project focuses on falls prevention through mobility assessment, the focus will be on the biological factors, those impairing sensorimotor function and balance control. However this does not include the non-modifiable factors, such as age, gender or race and chronic illnesses or impairmentsas they cannot be targeted for behavioural change.

Therefore the focus will be on targeting the decline in physical and cognitive capabilities and the balance problems the elderly might have.

1.1.4 Population ageing

In the Netherlands there are currently more than 3,3 million people over the age of 65, which corresponds to 19,3% of the total Dutch population (CBS, 2020) and the population is gradually ageing. The WHO states that the worldwide number of people over 60 years is growing faster than any other age group (2017). As a consequence, in the Netherlands, the prognosis for 2050 is that the number of first-aid visits for injuries after a fall in the elderly aged 65+ will increase with 47 percent to 160,000 ED-visits. For the people 70 years and older the forecast is an increase of 71 percent (CBS, 2018).

In addition, there is 'double ageing', meaning that within the group of over-65s, the proportion of over-80s is increasing. On January 1st, 2018, there were more than 779,000 people aged 80 and older in the Netherlands, representing 4.5% of the population (RIVM, 2018). This group being the most vulnerable contributes to population ageing being a challenge for falls prevention, as 50 percent are affected by a fall annually. The expanding group of seniors over the age of 80 years is expected to trigger a substantial increase in falls and fall injuries, see Figure 1.3. As researchers mentioned in 2007 already, a lot more preventative measures should be taken in the near future to prepare for this substantial rise (Kannus et al, 2007).

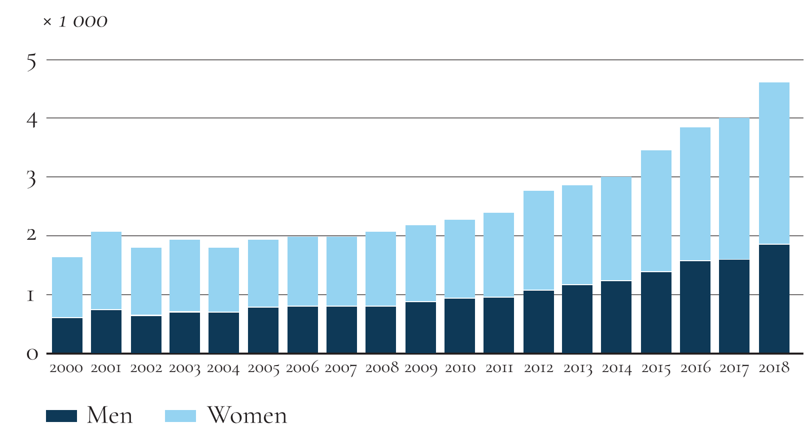
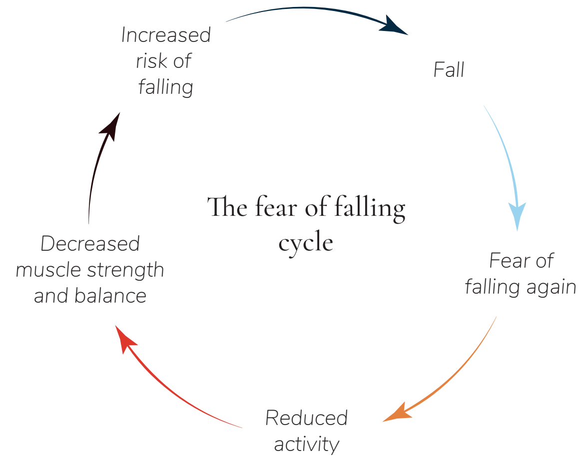


Figure 1.3: Deaths due to an accidental fall of the years 2000-2018, (CBS, 2019)

1.1.5 Fear of falling

Besides resulting in (lasting) disability and restriction in performing everyday activities, falls can also result in more psychological scars, in the form of fear of falling. Fear of falling (FF) is defined as a lasting concern about falling, leading an individual to avoid activities or become less independent (Tinetti, 1993). It is a serious issue to address as it is quite a common problem. Namely, FF is estimated to affect between 12% and 65% of community-dwelling older adults who have not previously fallen, and between 29% and 92% of fallers and frequent fallers respectively (Jørstad et al., 2005).

FF occurs both prior to and after the experience of a fall, resulting in the elderly becoming less active and less independent, due to a lack of confidence. This, in turn leads to activity restriction, causing social withdrawal and loss of independence. This may therefore unfavourably impact both physical and mental health, as the individual's mobility decreases, and the risk of future falls increases (Yardley et al., 2005). For this very reason, FF is also included in the list of intrinsic risk factors for falls, this cycle of FF is portrayed in Figure 1.4.



FF is, therefore, a legitimate focus for rehabilitation in the elderly as it can reduce someone's quality of life. Gaining confidence is one of the best ways to reduce fear of any kind and that could be the reason why Tai Chi lessons seem to work. They have proven to have an effect on both a physical and an emotional level, as it improves overall balance and mobility, giving the individual more confidence (Stevens et al., 2005).

1.1.6 Strategies of prevention

As falls and their subsequent consequences are bound to remain a major health care problem in the foreseeable future, more effective services need to be provided to address falls and fall risk in older people. Although numerous intrinsic and extrinsic factors associated with an increased risk of falls have been identified, the exact approach for the prevention of fall accidents remains ambiguous and unclear.

There are knowledge-gaps and questions about generability of interventions across specific age groups or settings for example. However, most studies state that targeted multifactorial interventions are more effective than interventions aiming to change one risk factor alone. Most approaches to accomplish prevention of falls are therefore multi-faceted and, generally, require two approaches (American Geriatrics Society, 2001):

1. An individual approach - services for individual patients referred for specialist management, and
2. A community approach - community programmes directed at populations of elderly people living in the community and at risk of falling.

For this project, and in order to provide a solution to the problem of falls among elderly, I will focus on finding a way of assessing the user's mobility through the design of a smart system embedded in the shoe. Hence, this design is meant for individual use.

The falls prevention technique could therefore be an add-on to the multifaceted approach described above.

Figure 1.4: The fear of falling cycle (Cifu, 2018).

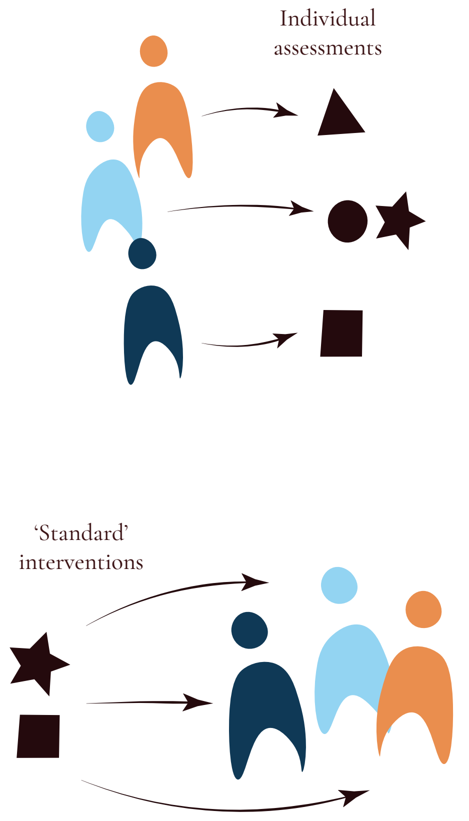


Figure 1.5: Visual representation of the two approaches used in multi-faceted falls prevention.

An individual approach identifies the individuals most at risk of falling and directs them to appropriate programmes using a dedicated falls prevention service. Although this approach is often more expensive, it has the great advantage of individualized risk assessment and tailored referral and advice (Campbell et al., 2007).

A community approach involves a focus on limiting extrinsic factors and education, e.g. keeping the outside environment clear and promoting awareness of the risk factors of falls (Tinetti, 2003).
When effective, this approach is prone to reach a far greater number of people and it is less expensive than the individual approach. However, this method does not address the individual's risk factors and there is no tool present to ensure an appropriate implementation of the recommended interventions (Cryer and Patel, 2002).

1.2 The human gait

This project is focused on preventing falls by establishing a real-time analysis of mobility patterns and gait imbalance, as it is established that many falls happen in the context of walking. Gaining theoretical knowledge about temporal and spatial measure of gait; how the variability therein can potentially increase fall risk, is therefore of great importance.

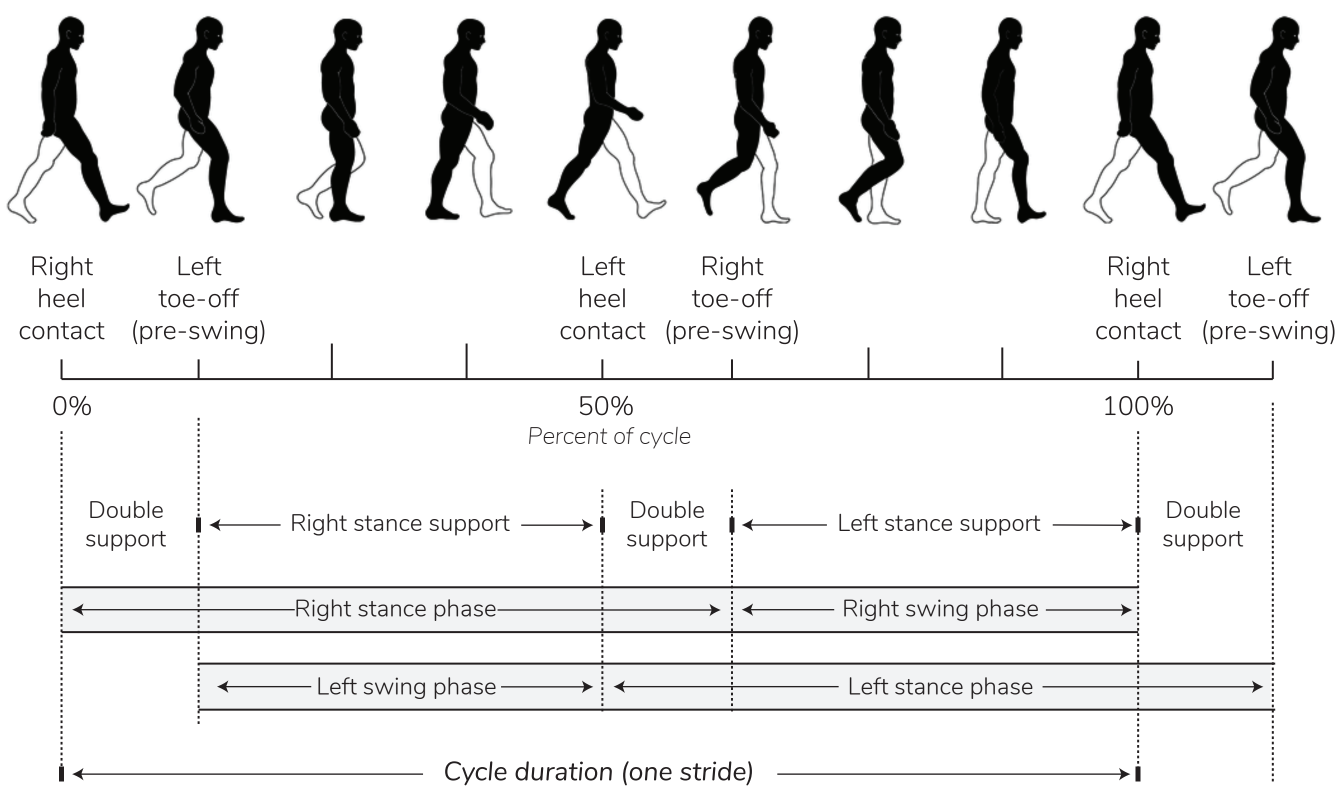
1.2.1 Definition

The gait cycle is defined as the interval of time between any of the repetitive events of walking (Murray et al., 1964). An individual's two legs have the same series of events, with a phase shift of one half cycle. One full gait cycle begins at the heel strike of one foot and continues until the heel strike of the same foot.

Within the human gait cycle, each foot performs one ground contact (stance phase or time) and stays on the ground for about 60% of the entire gait cycle. Consequently, the period where the foot is lifted off the ground (swing phase or time) accounts for 40% of the gait cycle (Larabi et al., 2020). The stance phase therefore begins with heel strike of one foot and ends with toe off of the same foot (Luximon, 2013).

More sub-phases within the stance- and swing phase are detailed in Figures 1.6 and 1.7.

Figure 1.6: Distance and time dimensions of a gait cycle (Murray et al., 1964).



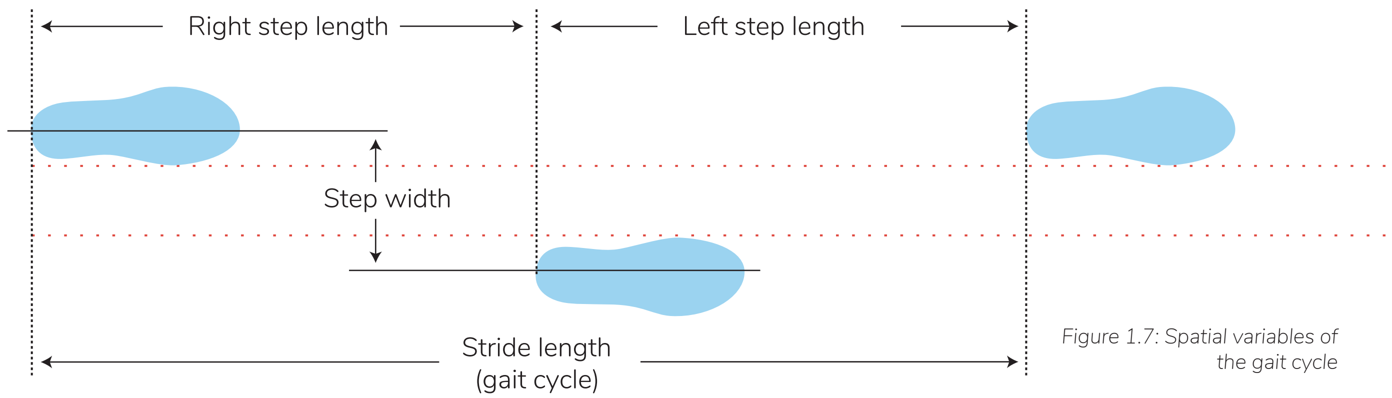


Figure 1.7: Spatial variables of the gait cycle

1.2.2 The gait up-close

A gait cycle is made up of gait parameters, extracted from the individual's feet placements and the time-series in which these occur. For the previously described focus of this research, some of these spatial and temporal measures of the gait cycle, when one is walking in a straight line on a level walkway, are researched. All definitions are extracted from the GAITRite electronic walkway technical reference manual (Inc, C. S., 2013).

Spatial (distance) parameters include

Stride length - The distance from the toe of one foot to the toe of the same foot in its next step. Stride length is two times ***the step length***, since this is the distance from the toe of one foot the toe of the other foot during walking.

Step width - A measure of the medio-lateral separation of the feet, the distance between the heels is a commonly used measure.

Temporal (time) parameters include

Stride time - The time elapsed between the first moments of contact of two consecutive footsteps of the same foot and it is expressed in milliseconds. Subsequently, step time is approximately half the stride time.

Single support and double support - Double support is the time when both feet are in contact with the ground. Naturally, single support is the time between the time when only one foot touches the ground. The single support corresponds to the swing time of the opposite foot. It is expressed in seconds and as a percentage of the total gait cycle time.

Cadence - The number of steps per minute.

Gait speed - The distance covered by the body per unit time, usually in metres per second.

Other spatio-temporal gait variables include

Gait asymmetry - Refers to the differences in the bilateral behaviour of the legs during walking, frequently related to step time, stride length or step length.

Gait variability - The changes in any of the aforementioned, and many more, gait parameters from one stride to the next.

Minimum toe clearance - The vertical measurement between the lowest point of the foot (most commonly the toe) to the walking surface.

1.2.3 Common age-related changes in gait

Ageing is a multidimensional process of change in the physical, mental, and social domains, leading to functional decline (Van der Cammen et al., 2017). Age-related decline in locomotor control often leads to falls and negatively affects one's quality of life and independence. A reduced gait speed is the most consistent age-related change (Cruz-Jimenez, 2017). Hence, this gait parameter is frequently used in geriatric settings as a quick, simple, and reliable way of estimating older patients' functional capacity (Rasmussen, 2019).

Decreased gait speed

Gait speed remains stable until about the age of 70; it then declines with about 15% per decade for a normal gait speed and 20% per decade for faster walking (Bohannon et al., 2011). Gait velocity slows down because elderly people take shorter steps at the same rate, resulting in a somewhat higher cadence.

Besides a decreased gait speed and higher cadence, other general differences in the gait cycle have been established between seniors and younger adults (Day et al., 2003).

Longer duration of double stance

Double stance time increases with age. The percentage of time in double stance goes from 18% in young adults to around 26% in healthy elderly people (O. Judge, 2019).

Shorter step length

Increased time in double support reduces the time the swing leg has to advance and thus shortens step length.

Increased gait variability

Overall, older age is linearly associated with greater intra-individual gait variability for most gait measures, except for step time variability in women (Callisaya, 2010). It is an important predictor of falls risk, but its exact characteristics are poorly understood.

1.2.4 Fallers vs. non-fallers' gait

As indicated, many falls occur in the context of walking due to age-related decline in locomotor control. However, there is limited research on what exact movements or changes in gait can lead to a potential fall (Rajagopalan,2017).

To be able to prevent a fall from happening, alarming changes in gait should be analysed and identified instantly, per individual. Hereafter, a potential future fall could be predicted and prevented.

> The product-to-be should therefore analyse and recognize significant and 'risk-depicting' variations in gait. This differs from the normal age-related changes in gait, as these are fairly general and do not pose as a threat per se.

To gain a better understanding of the variations in gait that could potentially lead to a fall, more in-depth research is conducted. Hence, characteristic differences between faller and non-faller elderly are reviewed in a literature review. The outcome of this study can be found in the following chapter, Chapter 2. The complete review, the manuscript, can be found in the Appendix A1.

1.3 Key insights and message

- Falls are a leading cause of injury among older adults, affecting one in three community-dwelling adults over the age of 65 and one in two adults over the age of 80 annually. These numbers will continue to rise due to population ageing.
- Falls in the elderly is a serious public health issue, the cause often being a combination of two or more risk factors. As most falls happen in the context of walking and this project focuses on falls prevention through mobility assessment, the focus will be on the biological risk factors, those impairing sensorimotor function and balance control.
- A multitude of interventions exists, as was portrayed in Chapter 1.1.6, and a combination of several of these might be the best way to prevent falls. However, none of the interventions showcase a real-time analysis of the level of fall risk as would be necessary to prevent falls. For this, research has to be conducted in products within the field of falls prevention through wearable devices.
- Fear of falling is an apparent problem in the elderly population, also posing as a risk factor, and must be carefully integrated in the to be designed intervention.
- Education on falls prevention through promoting awareness of the benefits of physical activity should be integrated in the to be design intervention. This should be kept in mind as the project moves along.

As phase (a) showed, there are several physiological age-related changes in gait, though, these are not necessarily related to falls. The risk factors impairing sensorimotor function and balance control leading to a potential fall, differentiating fallers from non-fallers, need to be further studied. Meaning, how are elderly fallers walking right before a fall?

This project aims to find out how technology could be implemented in the shoe to sense an impending fall through gait analysis and accessory interventions. Therefore, differences in gait between elderly fallers and non-fallers which could potentially lead to a fall need to be studied.

chapter 2

Literature Review

Parallel to the background research, a literature review was conducted to research the characteristic differences in spatio-temporal measure of gait between elderly fallers and non-fallers. Through identifying these gait and postural differences, the most suitable and viable gait parameter will be selected to be the focus of this project, and thereby be used as the base for the product.

In this chapter:

2.1 The approach
2.2 The results
2.3 Scope
2.4 Immersive testing
2.5 Key insights and message

2.1 The approach

Up until this point, it is established that the focus of this project will be on falls prevention through the analysis of mobility patterns, to be analysed by wearable technology located on or around the feet of the user. Now, the next step is to determine what these sensors will measure, which gait parameter shows the highest potential for intervention and is most viable to be used in the design of a smart shoe aimed at falls prevention?

In order to provide a solution to the problem of falls in elderly, this graduation project focuses on a way of making the elderly's everyday-shoes 'smart'. This will be realized by providing the shoes with built-in sensors, to be established later on as they are dependent on the outcome of this literature study. The user's mobility will be assessed through analysing the obtained data from these sensors, making it possible to identify, and thereafter, predict unsafe situations. Consequently, falls could be prevented through outputting this data to an accessory wearable or other tool/means, which will alert the user of the anticipated risk in an easy to interpret and non-intrusive manner.

2.1.1 Aim

Differences in temporal and spatial measures of gait between elderly fallers and non-fallers have been studied for numerous years. Namely, these dissimilarities are frequently used to detect fallers in clinical setups to facilitate strategies for falls prevention, for example. Through conducting a literature study, the aim is to uncover all presently known characteristic differences in spatio-temporal parameters of gait in elderly fallers and non-fallers, in order to be able to select the most appropriate gait parameter to be used in this project. In order to speed up the process, the study was conducted to solely include literature reviews, providing a wide range of data.

2.1.2 Approach

Before initiating the literature study, a main research question was set up. The literature research focuses on an analysis of gait and posture characteristic differences in older fallers and non-fallers, thus the research question addressed the following issue:

Main research question

What are the characteristic differences in spatio-temporal parameters of gait between elderly fallers and non-fallers?

Besides analysing and extracting measured gait variables, the literature study also aimed at gaining more knowledge on devices or other methods of measurement to extract the measures of gait, the test protocols in which these were integrated and, if applicable, the placement of the sensing technologies on the user's body.

Among other things, the study selection and characteristics depicted in each review and information on participants was reviewed and extracted. The manuscript included in Appendix A1 describes the full literature study in detail.

Based on the main research question and in line with the illustrated knowledge gaps, several accompanying sub-questions are set up.

Sub-questions

What are cost-effective technologies used to measure gait in older adults?

When body-worn sensing technologies are used, where are these sensors allocated on the body to collect the best data?

What are test protocols or methods used to extract the gait patterns? Which are most useful in what situation?

By using the software VOSviewer (Van Eck et al., 2013), a visual overview of the research field is constructed. The words from the titles, abstracts and key words derived from a search on concepts 1- 4 were exported and opened, outputting a 'keyword-map'. Through selecting 'gait parameter', numerous interesting and valuable terms were displayed that validated this project's focus. Namely, words like 'sensor', 'parameter', 'variability' and 'walking' were displayed. Additionally, other useful terms were extracted to be used for the next steps in this project. The keyword-map is showcased in Figure 2.1.

2.1.3 The literature search

The four most prominent concepts are derived from the main research question, as keywords, and these are combined with the loose term 'literature review', to limit the results accordingly and speed up the process, see Table 2.1 down below.

Table 2.1: Search terms and concepts used in the literature search.

	Concepts: combine with AND				
Search terms: combine with OR	Concept 1: Gait	Concept 2: Elderly	Concept 3: Fall	Concept 4: Risk	Concept 5: Systematic review
	gait	elderly	fall*	risk assess*	systematic review
	pace	old* people	slip*	risk analysis	
	step	aged people	trip*	risk evaluation	
	stride	old* folk$			
	walk	aged folk$			
	posture	old* person$			
		aged person$			
		old* adult$			
		aged adult$			
		senior$			
		ag$ing population			
		aged population			

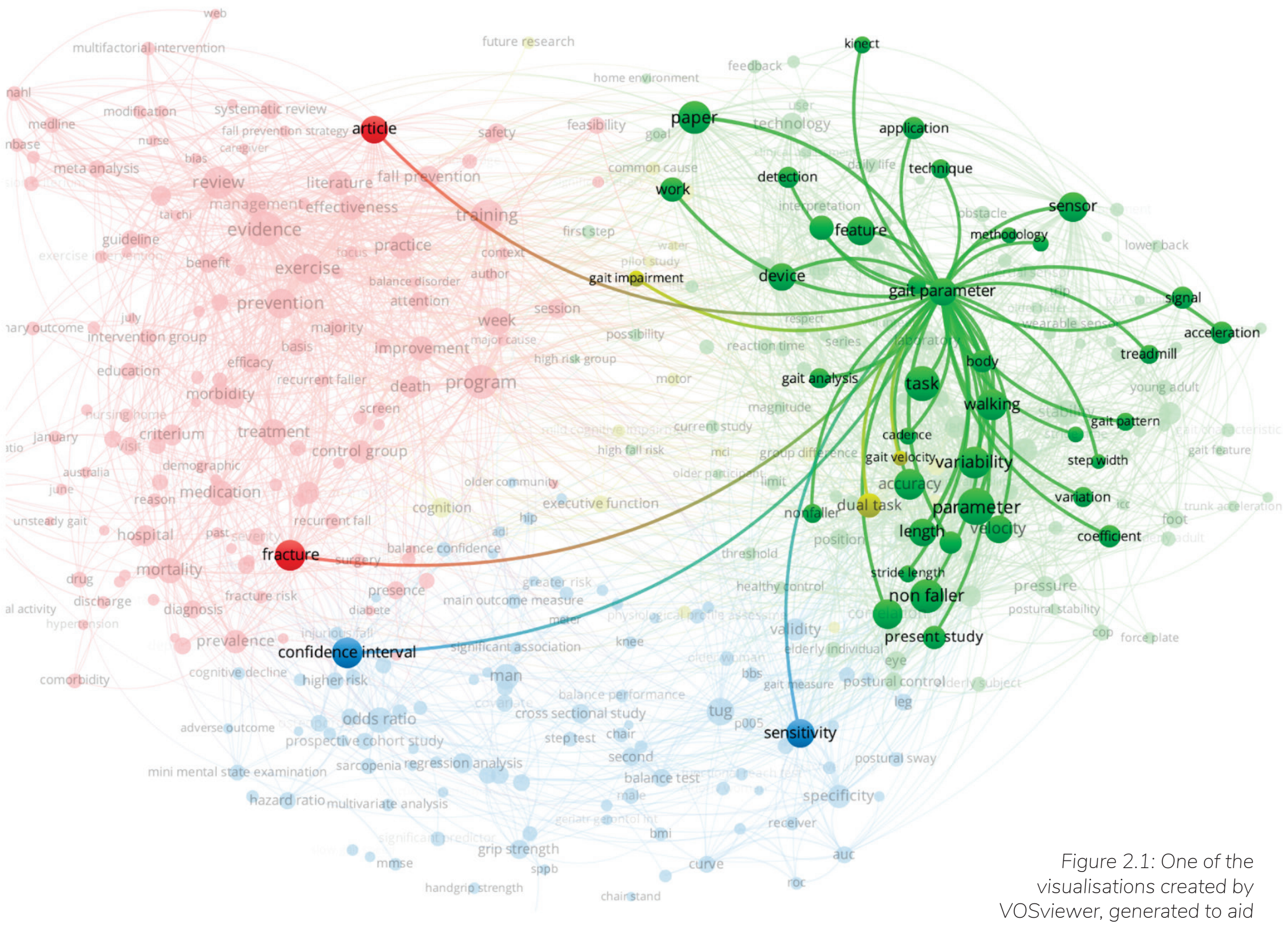


Figure 2.1: One of the visualisations created by VOSviewer, generated to aid the literature search.

Reviews were included in this literature study when they successfully met all of the following selection criteria:

1) Publications in the English language reviewing studies conducted in Western countries;
2) Reviews on studies analysing the differences in posture and gait of fallers and/or high fall risk older adults to non-fallers and/or low fall risk older adults, or studies regarding the sensing technology used to do so;
3) Reviews on studies focused on the healthy subset of the elderly population, aged 60 years and over;
4) Reviews describing the methods of measurement or types of sensing technology used in the studies;
5) Reviews on studies conducting fall risk assessments using accepted methods (physician screening e.g. or proven clinical fall risk assessment tools);
6) Reviews mentioning the level of significance or quality assessment of the data collected from the studies.

Titles and abstracts of the 65 (systematic) reviews identified through keyword search were screened against these selection criteria. Eight potential relevant articles were selected and retrieved for evaluation of the full text. Subsequently, through full text scanning, two of these articles were discarded, by not meeting the selection criteria. Any discrepancies were resolved via discussion with the supervisory team involved in the project.

After completing the study selection process, six systematic reviews remained and were included in this literature review. These articles were labelled A-F, and are presented in the table on the right, table 2.2.

Table 2.2: The six systematic reviews included in the final literature review.

A	Mortaza, N., Abu Osman, N. A., & Mehdikhani, N. (2014). *Are the spatio-temporal parameters of gait capable of distinguishing a faller from a non-faller elderly?*
B	Sun, R., & Sosnoff, J. J. (2018). *Novel sensing technology in fall risk assessment in older adults: A systematic review*
C	Patel, M., Pavic, A., & Goodwin, V. A. (2019). *Wearable inertial sensors to measure gait and posture characteristic differences in older adult fallers and non-fallers: a scoping review.*
D	Gillain, S., Boutaayamou, M., Beaudart, C., Demonceau, M., Bruyère, O., Reginster, J. Y., ... & Petermans, J. (2018). *Assessing gait parameters with accelerometer-based methods to identify older adults at risk of falls: a systematic review.*
E	Bet, P., Castro, P. C., & Ponti, M. A. (2019). *Fall detection and fall risk assessment in older person using wearable sensors: a systematic review.*
F	Hamacher, D., Singh, N. B., Van Dieen, J. H., Heller, M. O., & Taylor, W. R. (2011). *Kinematic measures for assessing gait stability in elderly individuals: a systematic review.*

2.2 The results

This chapter describes the results of the extensive literature search in a more concise matter, the more elaborate review can be found in Appendix A1.

2.2.1 Extracted gait parameters

Numerous gait and postural differences among elderly fallers and non-fallers or high- and low risk elderly are depicted in the six reviews. Due to project demands, i.e. regarding the available technology, the extracted gait parameters are limited to those which can only be obtained when one is walking in a straight line on a level walkway. Therefore, the following categories of variables of gait were excluded:

1) Linear acceleration variables,
2) angular velocity variables,
3) position and angle variables and
4) energy variables.

The aforementioned selection criteria on all parameters described in reviews A-F, yielded twelve spatio-temporal parameters of gait in elderly fallers and non-fallers or low- and high risk elderly fallers, suitable for this study and to be analysed in this research. So, the following gait variables were included in this analysis:

> Temporal gait parameters;
> **Cadence, step and stride time, step-time asymmetry, single and double support duration and gait speed.**
>
> Spatial gait parameters;
> **Stride and step length and step width.**
>
> The somewhat more complex parameters:
> **Minimum foot clearance and different measures of gait variability.**

These various measures and the number of articles that discussed these in each review are displayed in Table 2.3, on the right. For more information on the explanation of these parameters, see Chapter 1.2.2.

For each parameter / variable, an analysis was done on ((statistically) significant) data about this variable. Meaning, all findings related to (significant) difference(s) between faller and non-faller elderly or high- and low risk eldelry were included, per variable. Relevant articles to which the reviews referred were incorporated per research result, so that duplicate findings could be discarded. However:

What do these gait parameters tell us about the possibility to use them for the prevention of falls in the elderly?

In order to answer this question, all reports of parameter characteristics and findings were extracted, organized per parameter, and classified according to three 'degrees of value' for this project. Here, findings showcasing (1) significant relationships (or low risk of bias findings) on the twelve gait parameters, related to fall risk/ fallers, were decisive. Findings (2) stating valuable relationships between fall risk/fallers and the twelve gait parameters, but not (statistically) significant/ or at a moderate risk of bias, were also considered. Other study-findings (3) that refuted/ overturned the aforementioned findings, or depicting a lack of difference between the variable and fall risk were also acknowledged, as they are just as important. The various tables showcasing these results can be found in Appendix A2.

All information was thoroughly analysed in order to make an attentive decision.

Table 2.3: Number of times the variables were studied per review (in reviews A-F, includeing the devices used to obtain the measures and the placement of technology

	Devices used	Technology placement	Measured variables of gait
A	- Infrared camera motion analysis system with force platform - 6x - Instrumented gait measurement systems (GAITRite e.g.) - 4x - Accelerometers - 2x - Length-voltage transducer - 1x - Stopwatch - 1x - Foot switches - 1x - Filming & treadmill - 1x - Footprints on a paper walkway - 1x	NA	Cadence (6 studies) Stride time (3 studies) Stride time variability (2 studies) Single support duration (3 studies) Double support duration (5 studies) Gait speed (14 studies) Stride length (9 studies) Step length (7 studies) Stride/step length variability (2 studies) Step width (4 studies) Step width variability (2 studies)
B	- Inertial sensors - 17x - Video/depth camera - 2x (Kinect e.g.) - Pressure sensing platform - 2x (Wii balance board) - Laser sensing - 1x	- 11 on lower back (quantifying centre of mass movement) - 6 on lower limb, foot/shoe/shank/ankle (recording spatial/temporal gait parameters) - 3 used a body sensor network, a combination of the aforementioned placements	Cadence (2 studies) Gait speed (2 studies) Step time asymmetry (4 studies) Step time variability (1 study) Step time (8 studies) Step length (8 studies) Gait variability (5 studies)
C	The number of inertial sensors used varied between studies, with a range of one to five sensors A single triaxial accelerometer was most common, in 14 studies 6 studies: single wearable IMU 2 studies: 3 IMUs 2 studies: 5 IMUs	Posterior trunk: 22 studies 4 studies just said 'trunk'/'lower back'	Cadence (7 studies) Stride/step time (6 studies) Step time asymmetry (4 studies) Stride time variability (1 study) Single support duration (1 study) Double support duration (2 studies) Gait speed (15 studies) Stride length (10 studies) Step/stride length (9 studies)
D	Accelerometers	Different parts of the body; - accelerometers on forehead and the front of the sacrum - 2x - accelerometers on the lower back - 5x	Stride time (2 studies) Step time (2 studies) Step time variability (1 study) Gait speed (6 studies) Stride length (2 studies) Step length (1 study) Stride length variability (3 studies)
E	Four types of sensors were identified: - Accelerometer - 28/29 articles - Gyroscope - Magnetometer - Barometer	Waist region: 8 articles Lumbar region/lower back: 7 articles Pelvis: 4 articles Hand: 3 articles Ankle: 4 articles Other; 13 articles	NA
F	5 Categories of devices: - inertial sensors - foot switches (worn as insoles) - movement/ motion laboratory - walking mats - paper/ PVC mats	NA	Stride time (2 studies) Step time (5 studies) Stride time variability (2 studies) Step time asymmetry (2 studies) Double support duration variability (1 study) Gait variability (26 studies) Step length variability (2 studies) Step width (5 studies) Step width variability (1 study) Minimum foot clearance variability (1 study)

2.2.2 Faller characteristics

After thoroughly scanning all outcomes portrayed in the tables as reported by the aforementioned method, conclusions were made regarding twelve gait parameters. The results portrayed for five of these parameters were highly inconclusive and therefore ignored for this project. The reasoning for this can be found in the manuscript in Appendix A1.

Correspondingly, the following seven variables remained:

> Results show that elderly fallers have a tendency towards a **slower gait speed**, **longer stride and step time** and a **shorter stride and step length**. Also, **lower minimum foot clearance** and **more overall variability in the spatial and temporal measures of gait** were found to be linked to a higher risk of a future fall.

The seven above-mentioned gait parameters were discussed with the supervisory team. Subsequently, a focus was laid on one of these parameters, to form the basis of the mobility assessment product to be designed for this project. This selection and its argumentation can be found in the next chapter, Chapter 2.3.

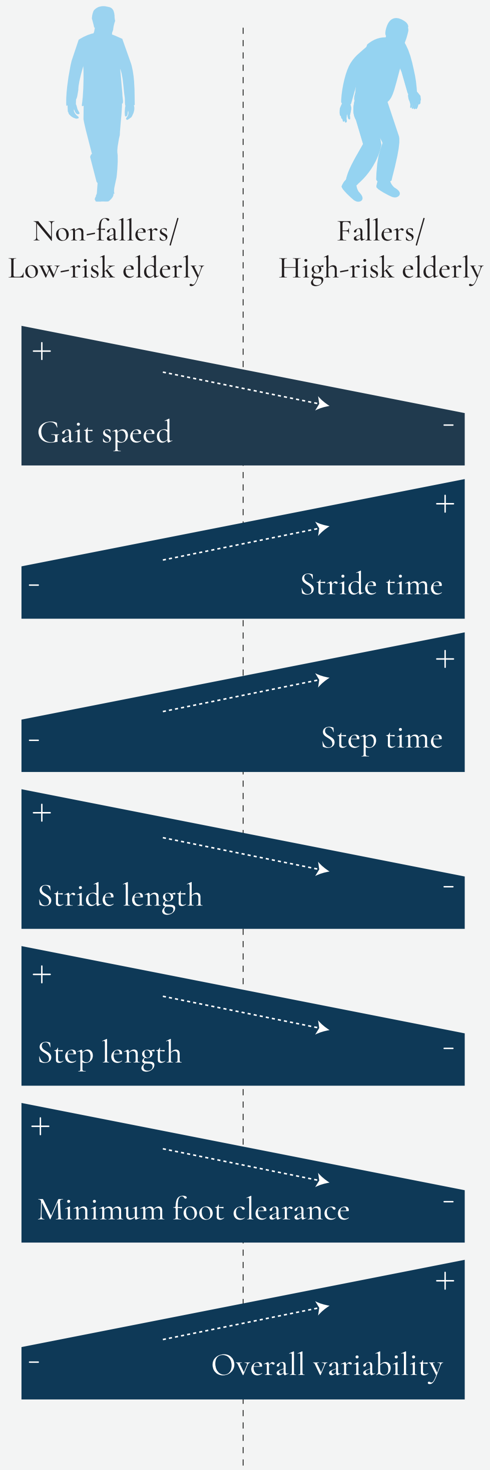


Figure 2.2: Characteristic differences between elderly fallers and non-fallers.

2.3 Scope

As the eventual product's built-in sensors will analyse the user's gait and signal the user when its assessment shows a potential risk of a fall, it is important to choose a gait parameter/marker that can be used to prospectively identify persons at risk of falling. From the seven remaining parameters linked to a higher risk of a fall, the minimum toe clearance parameters (MTC) were identified as the dominant variables. As the MTC is highly linked to leading cause of falls, namely tripping, as well as the smart system being located at the place in question, it is the necessary parameter to focus on.

As mentioned earlier in Chapter 2.2.2, the literature study showed that elderly fallers on average walk slower (decreased gait speed, longer stride and step time) and take more steps in a given period of time (shorter stride and step length). These characteristic differences between elderly fallers and non-fallers were most often acknowledged. The reason why these spatial and temporal measures are the most investigated is due to the fact that they are relatively easy to track through simple devices, e.g. a stopwatch and a tape measure. In contrast to spatio-temporal parameters, when analysing the MTC one needs a more elaborate test setup. This results in the MTC parameter being addressed much less frequently in the papers researched. As the eventual product will be a smart system placed in the shoe, the technology placement will enable analysis of this parameter.

2.3.1 Tripping

According to research by Berg et al. (1997) the two highest ranked activities in which elderly fallers were engaged at the time of a fall were (1) normal walking on a level ground or floor and (2) normal walking on uneven ground or floor, both at 24%, see Figure 2.3. Among the healthy elderly population (65 years and older), the predominant cause of falls during the activity of normal locomotion is tripping.

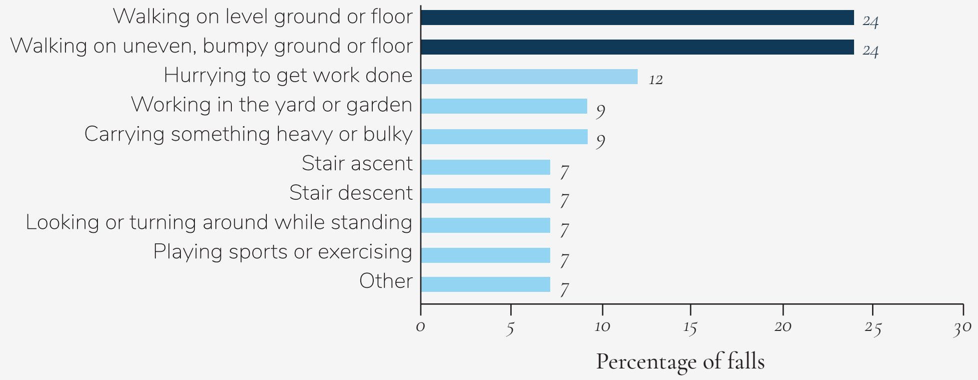


Figure 2.3: Activities in which fallers were engaged at the time of a fall (Berg et al., 1997).

The total exceeds 100% because fallers were requested to select all applicable options from a given list.

Trips have been reported to account for up to 53% of falls, see figure 2.4 (Blake, 1988). As the gait variable is directly linked to the event of a trip, there is a legitimate reason to focus on this parameter for the smart shoe design for this graduation project.

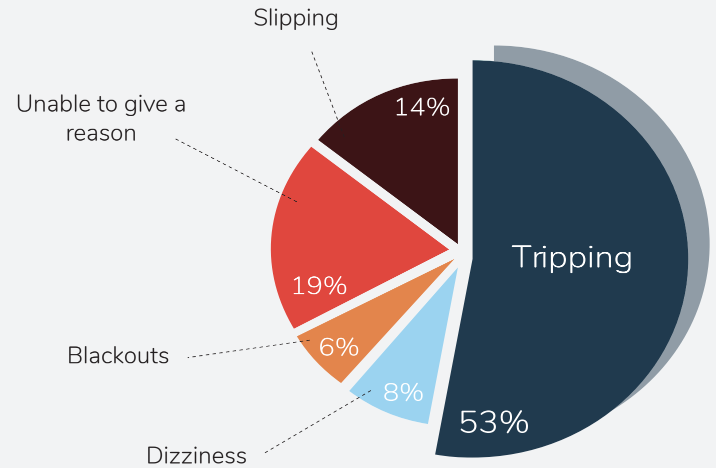


Figure 2.4: Self-reported reasons for falls in the elderly in a study by Blake et al. (1988)

2.3.2 The MTC parameter

The MTC is the minimum vertical distance between the lowest point of the foot of the swing leg and the walking surface during the swing phase of the gait cycle (Figure 2.5). At this instant, forward velocity of the foot is maximum and this high horizontal velocity paired with a low MFC increases the probability of unanticipated foot-ground contacts (Winter, 1992).
Roughly, at this moment in the gait cycle, the foot passes within 10-20 mm off the ground and the foot velocity is approximately three times the walking speed (Mills, 2001). It is a task highly sensitive to the spatial and balance control properties of the locomotor system and a key gait cycle event for predicting tripping falls (Khandoker et al., 2008). Since the goal of this project is to design a technological intervention to prevent falls, the MTC is an appropriate and suitable parameter.

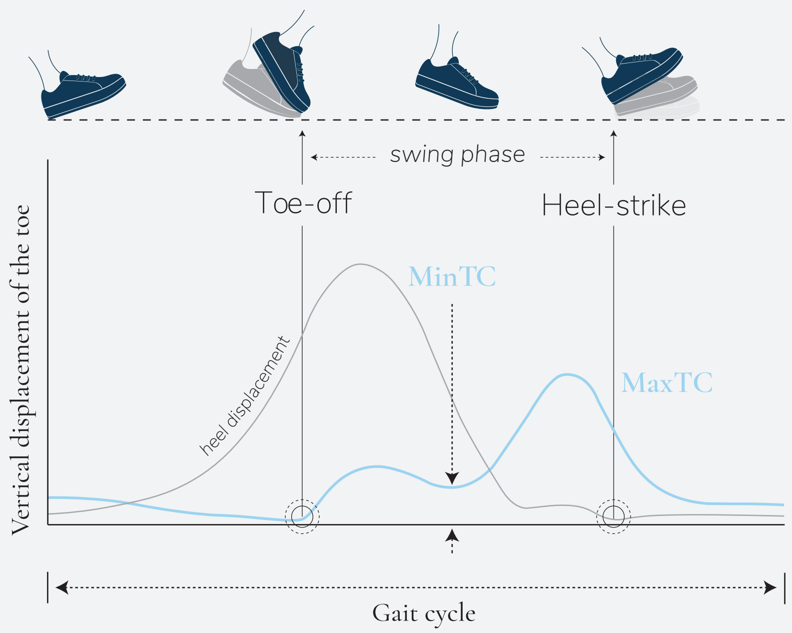


Figure 2.5: The minimum toe clearance (MTC) during walking, indicated by the light blue line (Blake et al., 1988).

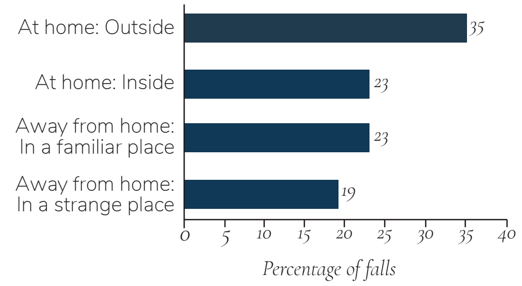


Figure 2.6: The location of falls (Berg et al., 1997)

2.3.3 MTC height and variability

Various studies report lower MTC values for older adults compared to younger adults, although none of these studies reported a significant difference in MTC height between the two groups. However, MTC variability was reported to be significantly greater for older adults. Optimizing MTC characteristics could therefore function as a falls-prevention intervention (Begg, 2019).

By shifting the MTC height to a safer margin and reducing MTC variability, the risk of a trip can be reduced for the elderly population. Begg (2007) and Barrett (2010) confirm this, as their studies also indicate that a low mean MTC combined with MTC variability could potentially cause tripping during walking in older adults compared to young adults, and elderly fallers compared to elderly non-fallers. However, studies are inconclusive on what the exact limiting margins are that define the high risk zone.

Proposed strategies
In the study published by Begg (2007), three possible strategies to minimize tripping risk are proposed:
- *Increasing median MTC height*
- *Reducing MTC variability*
-*Increasing skewness and kurtosis*

These strategies will be used later to validate the effect of the intervention-prototype.

The aim of this project is to design a product that provides real-time (visual) feedback to increase the MTC parameters, to make walking safer among the elderly. After deliberation with the supervisory team, the minimum toe clearance (MTC) is believed to be the most promising parameter to be used for this project.

This parameter can also be applied to the inside or outside environment, as independent of the extrinsic factors, elderly are not lifting their feet enough and the risk of tripping is present at all times and in any setting, see Figure 2.6.

2.3.4 Additional useful methodological features

Besides selecting the characteristic gait parameter that showcases great potential to identify possible oncoming falls, the devices and methods of measurement (including the placement of sensing technology) to obtain all gait parameters in the reviewed studies are also extracted. This information can be used in (pilot) test studies or further recommendations later on in the project. These include devices and methods of measurement, types and placement of sensing technology and test protocols applied.

Devices and methods of measurement

In the studies reviewed by papers A-F, different devices and methods were used to obtain the spatio-temporal parameters of gait (see Table 2.3). The most commonly used method involved the use of inertial sensors.

Advanced sensing technologies, like wearable inertial sensors (WIS), for assessing the measures of gait variability prove to be effective for identifying subjects with a higher fall risk and 'should be used when designing falls prevention strategies' (review E). WIS have the capabilities to objectively identify fall risk among older adults, even when clinical tests cannot.

In addition, obtaining gait parameters by motion analysis systems was also commonly employed, as a rather simple and cheap way to analyse one's gait. Additionally, simple devices, e.g. a stopwatch combined with a tape measure, allow for easy tracking of the temporal gait parameter gait speed. Hence this parameter was often studied throughout the reviewed literature reviews.

Review F depicting the study regarding the MTC parameters indicates that the parameters were analysed through a camera and motion analysis software setup. This was done to obtain the measures in a considerably faster pace, as opposed to having to build a smart system-prototype capable of doing this analysis. As this is a rather accessible technique to study this parameter, it will be used throughout this graduation project as well, see experiments i), ii) and iii).

However the final concept resulting from this project will aid to falls prevention through mobility assessment using sensing technology incorporated in the user's shoe. Hence, this smart system needs to be further explored in order do set up product requirements. Nowadays, inertial sensors, like accelerometers, their characteristics regarding size and price are viable to be integrated in a shoe. Therefor accelerometers w/ill be used to measure the MTC (variability).

Types and placement of sensing technology

Numerous studies used sensing technology to record spatial or temporal measures of gait, of which the accelerometer was used most frequently. Here, a single triaxial accelerometer was most commonly employed, often times placed on the posterior trunk or lower back, or the waist region. This was done so, in order to quantify centre of mass movement, usually capturing the parameter of gait speed.

Additionally, in some studies the inertial sensors were placed on the lower limb, at the foot, shoe, shank or ankle, recording the spatial and temporal gait parameters.

Noticeably, the inertial sensors will be placed in or around the shoe, in order to measure this gait variable. Some other studies depicted in the review had their applied sensors placed on this same location, though, little information could be found regarding the exact specifics.

Test protocols

To retrieve the spatio-temporal measures of gait, various test protocols were used throughout the studies depicted in reviews A-F, though, the steady state walking test, in a self-selected or normal walking speed, was by far the most commonly used test method (more can be found in Appendix A1 and A2). Additionally, reviews B and E include studies that used functional mobility tests, such as the Timed-Up-and-G0 test, Tinetti score and the Sit-to-stand test.

When a pilot test will be employed in this project, the steady state walking test (in a straight line) will be used as test protocol. This was by far the most commonly used test method used in the reviewed studies. Later on it will be decided whether this will be in a self-selected or pre-programmed walking speed, dependent on the test setup.

2.4 Immersive testing

In order to learn more about the MTC parameter and the human locomotion, several pilot tests were conducted using the video analysis and modelling tool Tracker.

Similar to how the MTC is researched in papers, but opposite to how it should be analysed in the eventual product, motion tracking software is used to study the MTC parameter.

Two different pilot tests can be found in the following pages: i) software validation and ii) effects of the footwear on the MTC. With these tests, the aim was to get to know the software medium, dive deeper into the human gait and to verify whether this program could be used in future tests when evaluating the final design.

Experimental research

i) Software validation

Baseline test, validating the analysis-tool

At first, through primitive testing in the home-setting, the available tools of the program were explored to be used in a more advanced setup later on.

Aim

Since it is not possible to use inertial sensors for the experimental research in this project, video analysis software was tried out to act as a subsistute, similarly to the reviews described in Chapter 2.3.4.

Method and procedure

With the use coloured post-it 'markers' positioned on the toe and heel of the test subjects' shoe and a fixed camera positioned parallel to the 3 m walkway, various walks were recorded. The initial test had the aim of establishing whether the differences in the gait cycle between normal walking and shuffling could be portrayed in the graphs outputted by the software. As the minimum toe clearance is related to a shuffling gait (short, low steps), distinct differences in gait parameters should be made visible when walking normally and during a shuffling walk.

During these initial tests, two test subjects were asked to walk two times in their preferred walking speed/ normal walking manner in a straight line, on a flat level walkway measuring 2 metres. Subsequently, the test subjects were asked to engage in a more shuffling type of gait, being performed twice by both as well.

Data analysis

The eight videos were loaded into the software tool Tracker see Figure 2.9. The obtained sets of data on the gait were analysed by tracking both the minimum heel clearance (MHC) as the minimum toe clearance (MFC), of which the latter is mostly used to measure the MFC. The y-position components versus time were plotted for both parameters, and as a validation, the graphs were compared with the 'standard' vertical displacement of the MTC recorded in various types of literature (see Figure 2.5). The MTC displacement in the graphs outputted by Tracker were quite identical to these, validating the use of the software, after which analysis was initiated.

Results

The results showed that for all four shuffling gaits, both the MTC and the MHC returned lower vertical distances when being compared to the four normal gaits of the corresponding test subject. An example of this can be viewed by comparing Figures 2.8 and 2.9; the values of the MTC (see the light blue circles) are lower in the shuffling gait graphs.

Conclusion

This pilot test confirms that the motion analysis tool is able to display the previously identified differences by between a normal- and a shuffling gait, acknowledging that, generally, the foot swings closer to the ground during a shuffling gait (Mills 2001).

More importantly, this test validates that the tracker-software is a satisfactory tool to represent what the eventual product should analyse. The software outputs graphs that are very similar to the one portrayed in Figure 2.5 in Chapter 2.3.2, as can be seen in Figure 2.7 down below. Therefore, this technology will be used in future testing regarding the MTC and the impact of the to be designed product therein.

All eight graphs resulting from this small study can be found in Appendix A3.

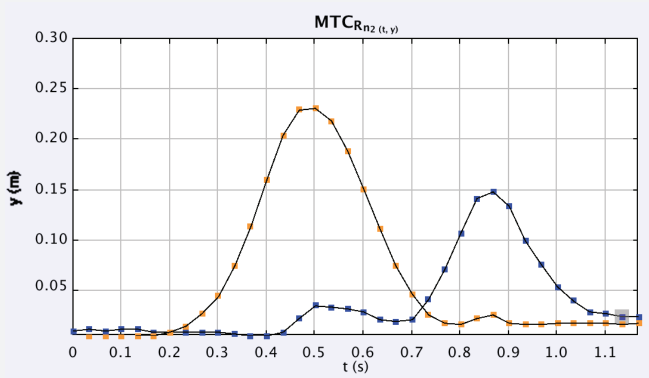


Figure 2.7: Vertical displacement of the MHC (orange) and the MTC (blue) during normal locomotion, extracted from the Tracker software.

Figures 2.8 and 2.9: Vertical displacement of the MTC for test subject 1; for a normal gait (left) and a shuffling gait (right). The light blue circles and lines represent the decrease of the MinTC and MaxTC height for the shuffling gait.

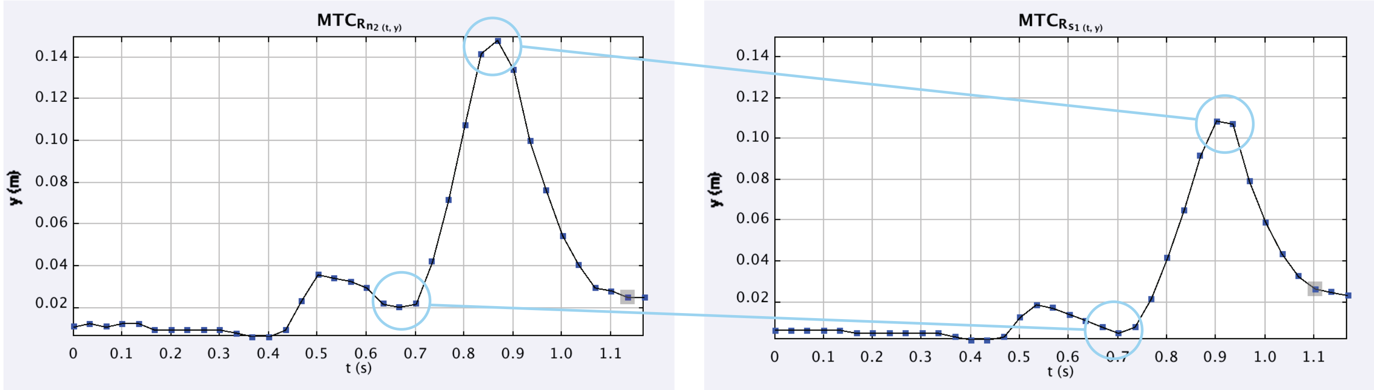


Figure 2.10: Frame from a video imported in Tracker. The red dot marks the toe, tracking the MTC parameter.

ii) Effect of the footwear on the MTC

The effect of footwear on the MTC

As the software now proved to be a satisfactory and accessible method to analyse the MTC variable, and therefore mimic what the envisioned prototype should analyse in real-time, it was used once more, though, for slightly different purposes.

The supervisory team of this graduation project has been researching shoe design for older adults, as good shoe design is important for stable balance and gait performance and optimal footwear could therefore be used as a preventative factor for falls (Jellema et al., 2019).

Aim

To elaborate on this topic, it was studied whether different types of footwear have a substantial effect on the MTC as well. If so, this could be a possible indicator that the person should change to a more supportive type of footwear (when possible), when the risk of a fall, due to increased MTC variability, is high. Hence, this information could be implemented as potential output on the product-design ('wear different shoes'), when signalling the user if fall-risk is increased.

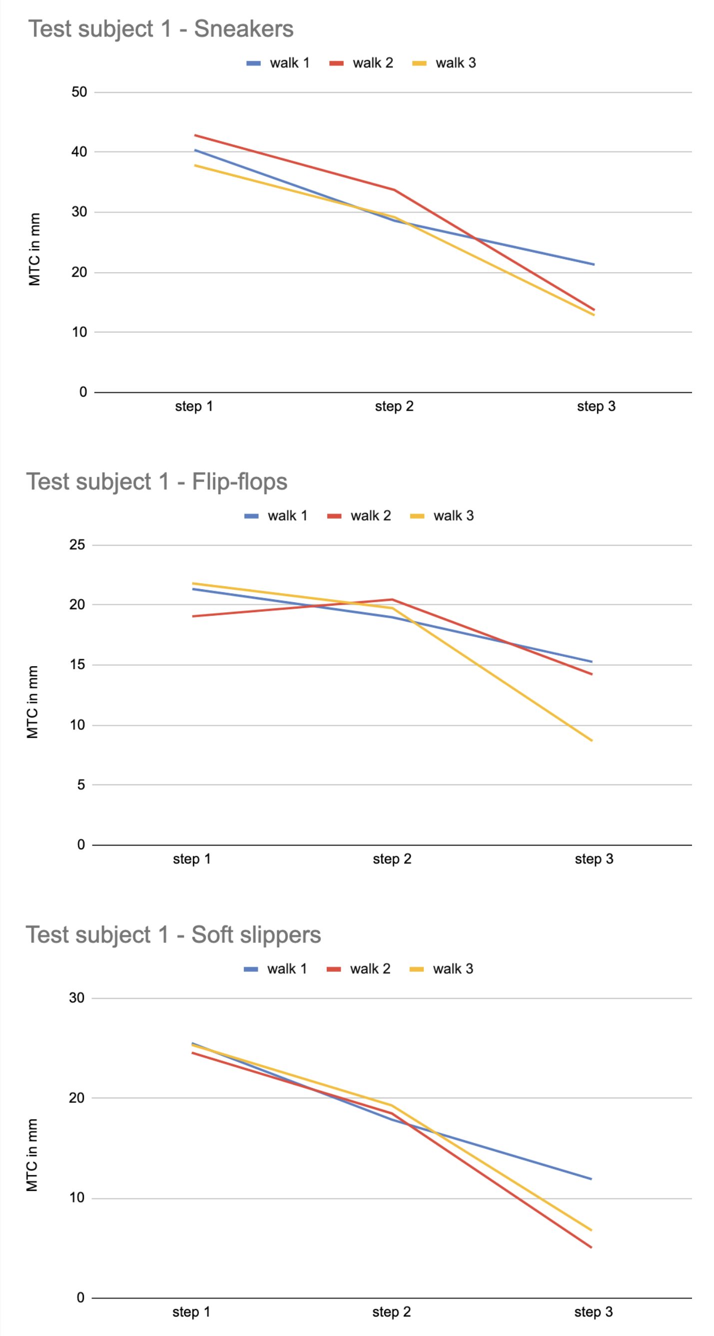
Method and procedure

During this second pilot test two test subjects both wore three different types of footwear: sneakers, slippers and flip-flops. Both test subjects walked the flat-level walkway three times for every worn pair, and in all 18 analysed videos, the test subjects completed at least 3 strides / gait cycles. Hence, a total of 54 MTC-measures were analysed.

Data analysis

The absolute values of the minimum toe clearance were extracted from the tables, though they do not showcase a correct representation as the toe-off value differs per step. Accordingly, for each individual step the toe-off values were subtracted from the MTC's absolute values of each corresponding step. Half of these outcomes (for test subject 1) can be found in Figures 2.10-2.12. The test setup was primitive but results were encouraging.

For all steps of the same footwear used per test person, the mean MTC in mm was calculated to find whether there are characteristic differences to be found. As can be seen in Figures 2.10-2.12, the last



Figures 2.10-2.12: MTC (in mm) for test subject 1. The data is displayed per worn type of footwear and the graphs include the three walks of 3 strides each (3 steps of the tracked right foot).

Table 2.4: Mean MTC in mm per type of footwear.

Type of footwear:	Sneakers	Flip-flops	Soft slippers
	Test subject 1		
Mean MTC of all steps	29,94 mm	17,73 mm	17,19 mm
Mean MTC of the first two steps per walk	35,43 mm	20,33 mm	21,83 mm
	Test subject 2		
Mean MTC of all steps	38,75 mm	22,19 mm	19,85 mm
Mean MTC of the first two steps per walk	39,98 mm	25,77 mm	25,07 mm
	Test subjects 1 + 2		
Mean MTC of all steps	34,35 mm	19,96 mm	18,52 mm
Mean MTC of all first two steps per walk	37,71 mm	23,05 mm	23,45 mm

step had a considerable lower foot clearance (15 out of the 18 walks). One thing that might explain this, is that the walkway ended quite abruptly as the end of it was about 30 cm away from a wall. The test subjects might have held back for that final step and this could have resulted in distorted measures. For this reason, two rows were added to the table, excluding the third step from every walk, see Table 2.4.

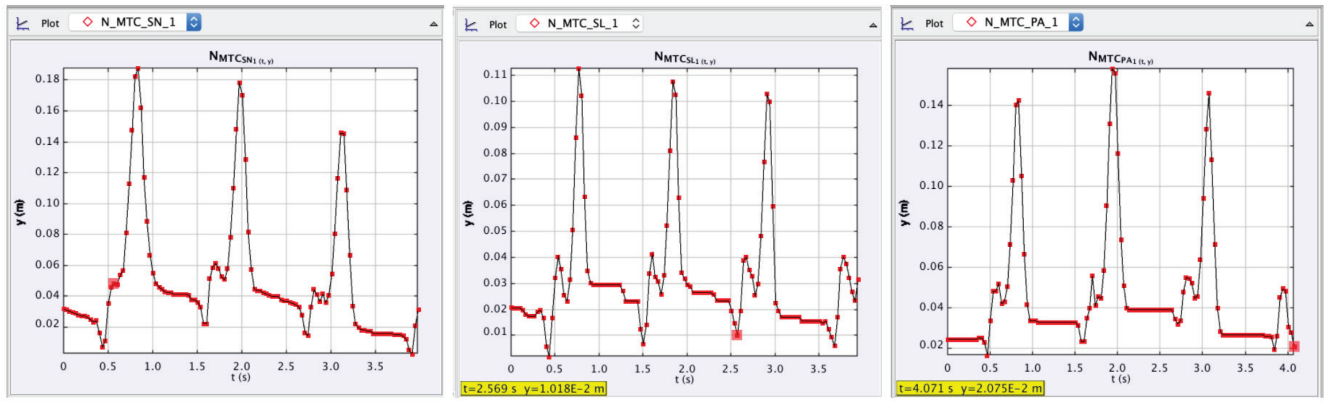
Results

Distinct differences in the height of the MTC when walking with different types of footwear are illustrated. The mean MTC of both test subjects increased around 15 mm when wearing sneakers as opposed to wearing flip-flops or soft slippers (see highlighted part in table 2.4).

The lowest absolute value for MTC was 5,04 mm and showcases the extent of how close the foot can swing above the ground, and therefore the lurking risk of a potential trip or fall. However, these measures are prone to imprecision due to the primitive test setup and accessory concerns (see discussion in Appendix A4).

Additional to the measured outcomes, other things stood out as well. When looking at Figures 2.13-2.15, distinct differences can be found when comparing the gait cycles when the test subjects wore the different types of shoes. Sneakers tend to have a predominantly large(r) rounded toe which helps in the unwinding of the foot during daily walking. This is clearly visible in Figure 2.13, where the vertical displacement of the MTC is barely ever 'flat'. In contrary, this 'flat' line is very much visible in Figure 2.15, as soft slippers don't have a supportive sturdy toe to enable this rolling motion.

Figures 2.13-2.15: Vertical displacement of the MTC (or PTP) for three gait cycles for sneakers, flip-flops and soft slippers (l-r).



Conclusion

As mentioned before, the Tracker software proves to be a satisfactory and accessible method to analyse (the effects on) the MTC variable. Therefore, eventually, this tool will also be used to measure the effect of the technological intervention, when the user is signalled to improve their gait (and thereby increase their MTC) when fall-risk is present.

The second pilot test regarding footwear, showcases the substantial effect of soft shoes of slippers on the MTC. This finding will be included in the final design of the product.

2.5 Key insights and message

- From the literature review it was concluded that the minimum foot or toe clearance variability parameter shows the most potential for this project.
- After determining that the MTC parameter will form the base of the falls prevention-intervention, more in-depth research needs to be conducted in order to understand how technology could capture and analyse this variable.
- Of all test protocols used throughout the reviewed studies, a steady state walking test on a level walkway was used most frequently. When a pilot test will be employed in this project, this setup will be used as test protocol as it is most accessible and in line with the project requirements.
- A low mean MTC combined with increased MTC variability could potentially cause tripping during walking, therefore the intervention needs to optimize both these measures to effectively improve one's gait and prevent suspected falls.
- Small pilot tests have shown that the motion analysis software Tracker proves to be a satisfactory and accessible method to analyse the MTC variable. The experimental tests validate that the tracker-software is a satisfactory tool to represent what the eventual product should analyse. Eventually, the software could therefore be used to research the effect of the product to be designed.
- Secondary pilot tests have confirmed previous studies on the effect of footwear on the MTC. Wearing sturdier, more supporting shoes, improves the unwinding of the foot and results in a more 'active' walk. Incorporating the recommendation in the app could add to the concept of an improved gait.

Phase (b) showcased a concise version of the literature review conducted to find the characteristic differences in gait parameters between elderly fallers and non-fallers. The MTC parameter is believed to be most appropriate to use for this thesis. Considering the complexity of the solution space and the available time in which to, eventually, present a meaningful and interesting falls prevention-intervention, the MTC parameter is most interesting and feasible to use as a measurable indicator of a possible future fall.

The next step is to further research this gait variable and the optimization thereof, and to find out what the target group's opinions are on this proposed behavioural change.

chapter 3

Contextual Analysis

This chapter shows interesting insights gained by conducting immersive studies into the wearable health technology. Additionally elderly's needs and wants are explored, through a user-centered approach with the target group. Expert knowledge derived from interviews enriches this pool of information. Lastly, theories of persuasive design and user adaptation are researched, in order to understand the requirements of a product aimed at behavioural change.

In this chapter:

3.1 Sensing and wearable health technology
3.2 The target group
3.3 Expert knowledge
3.4 Behavioural change
3.5 User adaptation
3.6 Key insights and message

3.1 Sensing and wearable health technology

Now that the focus lies on the minimum toe clearance (MTC), it is important to understand how this parameter could be measured and analysed. What type of hard- and software is needed to capture one's gait characteristics. Additionally, to gain a better understanding of the market, current products using these types of sensing technology will be researched.

Existing sensing products to measure gait parameters are researched to what the technical architecture of the designed product could look like. For now, all (pilot) testing is done using motion analysis software. However, as the eventual product is a smart shoe with embedded smart system, this sensing technology will need to be explored.

3.1.1 Sensing technology to analyse the MTC

Gait analysis is the study of the human locomotion, involving the measurement and assessment of parameters that characterize the human gait (see Chapter 1.2). As presented in Chapter 2.3.4, this analysis of gait measures is often performed using wearable sensors, as it is an inexpensive, convenient, and efficient method to do so (Tao et al., 2012).

As was concluded in Chapter 2.3, throughout the studies reviewed, inertial sensors were by far the most used type of wearable technology to measure gait parameters. Accelerometers, crucial parts of an inertial sensor, have been used to monitor the motion of human movement as early as the 1950s (Imman et al., 1953). Due to their small size, they are often being used in wearable devices with the aim of motion tracking.

In order to analyse the MTC in this project, as well as other gait parameters, an inertial measurement unit (IMU) with an accelerometer will be used, similar to reviews A-F, presented in Chapter 2.3 Alongside the accelerometer, IMUs also typically include a gyroscope and a magnetometer. An accelerometer measures acceleration, or the rate of change of speed, of the device. Accelerations are measured in three different directions, also known as the X-, Y- and Z-axis. A gyroscope measures the speed at which the sensor rotates around these three axes, also called angular velocity, see Figure 3.1. Finally, the magnetometer measures the strength of the magnetic field, again in these same three directions.

These three sensors together allow the IMU to collect the raw data necessary to initiate calculations.

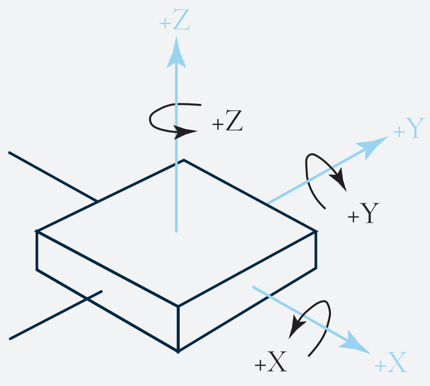


Figure 3.1: Acceleration and angular velocity.

From a technical point of view, the use of an IMU sensor is most optimal to be built in the shoe. IMU's are as small as a human fingernail and therefore they could, for example, be easily integrated in the mid- or insole of the shoe (C. Glaeser, 2019).

However, similar to all type of sensing technology, an IMU sensor should be used in combination with other electronic hardware. To gain a better understanding of the sensors used in geriatrics gait research, and the framework in which they operate, an overview is constructed.

A rough depiction of the technical components and subsequent architecture necessary for the analysis of the gait parameters can be viewed on the right in Figure 3.2 (GaitUp Company, 2020) (Venkatesware et al., 2018).

Other required hardware

Besides the sensing technology, other components need to be integrated in the smart system as well, to enable a real-time and ongoing analysis of the MTC, to transmit this data to a database and to enable interaction with the product, for example.

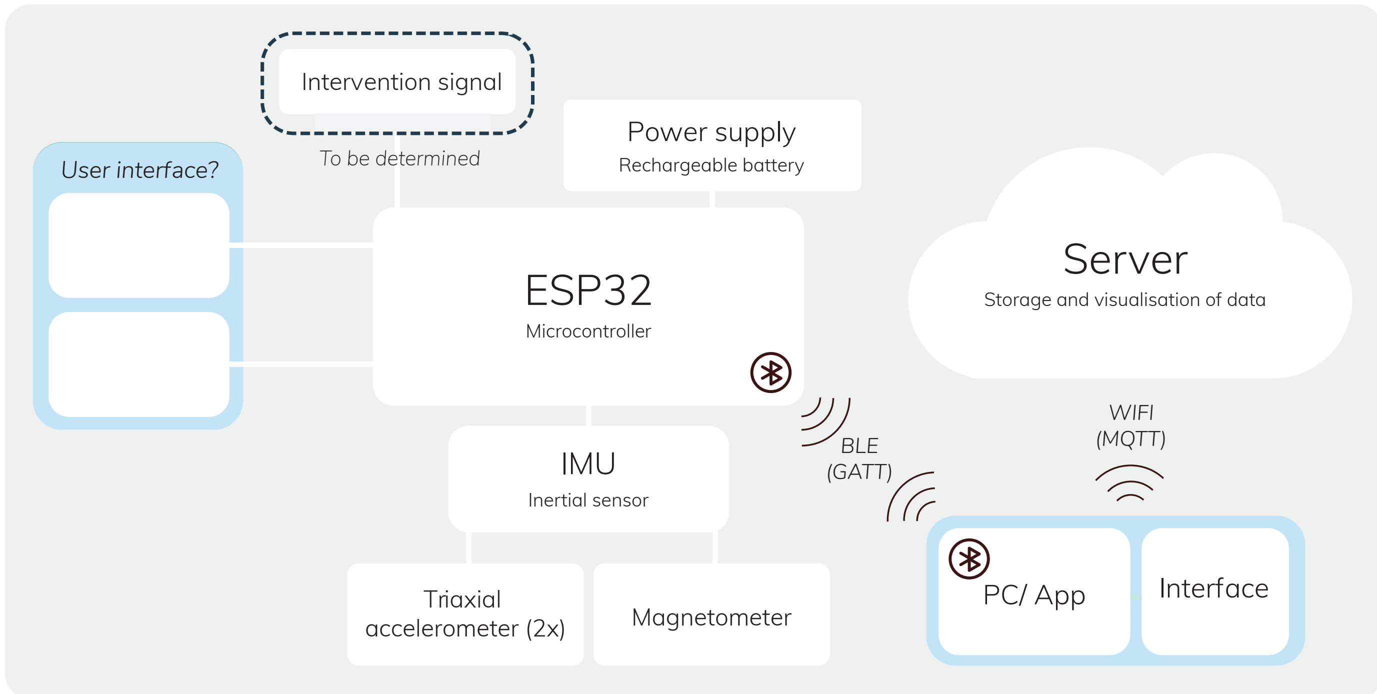
An ESP32 will be used, which is an advanced Arduino enabling a Bluetooth and a Wi-Fi connection. This microcontroller forms the basis of the device, as it holds all other components. In order to store data, a Bluetooth connection will be set up. The sampled data is serially fed to a Bluetooth module and transmitted to an App, which is also interfaced to a Bluetooth module. The block diagram in Figure 3.2 presents the (general) technical architecture of the smart shoe, although, prone to imprecision.

The intervention signal (actuator) will warn the user when unstettling MTC height or variability is detected. This central part of the product, the intervention, will be elaborated upon in Chapters 6.2 and 6.3.

The system's architecture will also be able to measure all other spatio-temporal gait parameters depicted in Chapter 2.2.1. Therefore, combining the analysis and data of these parameters with the intervention targeting the primary variable of the MTC, fall-risk assessment will be further optimized.

Whether the smart system has a user interface, the integration of it in the shoe and further elaboration on the smart system is depicted in Chapter 6.1.

Figure 3.2: Rough depiction of the technical architecture of the smart shoe-components.



3.1.2 Wearable health technology

Besides analysing the gait, the eventual product also needs to signal the user and display important information. Wearable technology, or wearables, use such hardware components to measure body signals.
Wearables are smart electronic devices that are worn close to or on the surface of the skin. Here, they detect, analyse, and transmit information concerning specific body signals; in some cases allowing immediate biofeedback to the wearer (Dias et al., 2019). Given that such a device can easily collect data concerning an individual, as it is in close contact with the user, wearable technology is often used to monitor a user's physiological status. Therefore, learning more about these products is evident for this project.

3.1.3 General types of wearable devices

The rapid advancements in wearable technology and the popular demand from consumers to take control of their own health has influenced the medical industry to develop more and more wearable devices. These personal devices are designed to collect the data of a users' personal health and exercise, for example, offer assistance in physical training programs.

Specifically, nowadays, wearables can be used to collect all kinds of data, including heart rate or blood pressure, release of certain biochemicals, calories burned, steps walked or time spent exercising in general. Usually, these functions are combined and integrated in a single device, such as an activity tracker or a smartwatch, see Figures 3.3-3.6.

Figures 3.3-3.6: Wearable devices: The Fitbit, Omrom's HeartGuide blood pressure monitor, Apple Watch and Philips' Biosensor

Figure 3.7: The Empatica Embrace, a wrist-worn wearable in the field of epilepsy, with an accessory app.

Benefits

Encouraging proactive healthcare benefiting everyone

Watching how many calories you have been burned or finding out how well you're sleeping; features like these are made possible with the introduction of wearable technology. Thereby, bringing along considerable health benefits.

With the introduction of wearable health devices, along came the potential for a more proactive approach to healthcare. The devices can be used to take action in the early stages of a health issue. Irregularities, for instance, for people prone to health problems, can be detected before the person notices it themselves. The products provide data that can help health professionals diagnose issues faster and intervene sooner, to prevent hospital readmissions or other negative consequences (Bove, 2019).

In this way, the devices benefit healthcare providers and employers, as the data generated by them can be used to improve diagnosis or treatment. Accordingly, vulnerable patients could be monitored with such a product. Notifications can be sent to the user's family or physician after an emergency (a fall e.g.) helps in speeding up the process and decreases the chances of problems developing into larger issues.

Shortcomings

One-size-fits-all shortcomings and privacy concerns

Even though wearable technology is improving health care in various ways, there are also several product shortcomings such as technical difficulties, poor data quality and settings that are too generic.

Aside from the seizure-alerting wearable Empatica Embrace in Figure 3.7, for example, most wearables have limited abilities in analysing or making conclusions based on the data they collect. Therefore, most wearable technology products are primarily used for general health information and showcasing. Aside from the devices accounting for biological differences between individuals, there are still numerous wearable devices that collect data and apply one-size-fits-all algorithms, resulting in highly generic analyses. Accessory to this shortcoming, some wearables have been reported to measure data inaccurately on occasion. This can be especially dangerous when measuring data like heart rates.

Besides the absence of consistent quality and certainty, there is another concern: security. As any form of online activity leaves a trail, so do wearable devices. All connected devices generate an excessive amount of data, which other (third) parties, employers e.g., could repurpose for objectives other than health. Therefore, more and more research and studies are being conducted to investigate the limitations of this innovative technology (Anaya et al., 2018).

3.1.4 Wearable products in the field of fall detection/prevention

As stated in Chapter 3.2.2, the market for wearable health technology is growing. In the recent years, the topic of falls among the elderly has been gaining momentum and numerous efforts have been made in designing a product to alleviate this problem. Here, various products are showcased that are currently (almost) on the market. Some products are merely aimed at detecting falls and do not include the ability to prevent possible oncoming falls.

Falls detection

Smart pyjamas - The eSkin Sleep and Lounge set by Xenoma is smart apparel for the well-being and health monitoring of elderly people. The clothing is capable of detecting falls, monitoring overall activity and tracking sleep patterns. While still being at concept level, the product is not on the market yet (Figure 3.8).

Smart connected eyewear - Ellcie Healthy designs smart connected eyewear with AI to monitor people and prevent risks like drowsiness at the wheel. It also includes fall detection and activity tracking. If a fall is detected, for instance, an alert will be sent to the product wearers' family or physician. To expand on fall detection, Ellcie Healthy is currently working on a falls prevention solution, in collaboration with Nice University Hospital (Ellcie Healthy, 2020) (Figure 3.9).

Figures 3.8 and 3.9: The eSkin Sleep and Lounge smart pyjamas by Xenoma and the smart connected eyewear by Ellcie Healthy.

Falls prevention

Smart belt - The WELT Smart Belt Pro aids in falls prevention by analysing the wearer's walking pattern to detect the risk of falling. The product holds numerous sensors that analyse (abnormalities in) the gait, such as walking speed or levels of symmetry, and will send a warning to the user's phone once an unstable gait is detected. Additionally, the data can be shared through smartphones to help caretakers and physicians monitor patients (Figure 3.10).

PhysiLog inertial motion sensor - This company uses intertial sensors which provide biomechanical parameters useful for a range of applications in the field of sports and health, i.e. aiding rehabilitation. GaitUp has developed the PhysiLog, an inertial motion sensor to measure gait With this product, which is placed on the shoe, movement disorders can be measured to quantify and detect pathological gait. This product is targeted at health professionals, enabling them to improve their geriatric research (Figure 3.11).

Figures 3.10 and 3.11: The Smart Belt Pro by WELT and the PhysiLog by the GaitUp company.

Insights

One great attribute of the first three products, is that they are integrated in an accessory, item or piece of clothing. This benefits the user in not having to wear an additional stand-alone product. All products are WI-FI or Bluetooth connected, meaning that alerts or information is displayed on a second device.

WELT's Smart Belt Pro is currently the only known product that sends real-time warnings to the end-user, enabling instant falls prevention. As the PhysiLog is targeted at health professionals, the product aids geriatric assessments and does not prevent falls real-time. However, the PhysiLog, a small transferable device which can be attached to the wearer's shoe laces, measures 26 different gait parameters, numerous more than the smart belt. This is made possible by the placement of the product, which is around the shoe.

3.2.5 Solution / design space

All featured products make use of inertial sensors to measure the various gait parameters needed for falls detection of prevention. As the PhysiLog is attached to the user's shoe, it allows for a more extensive analysis of the gait. The placement also allows for analysis of the MTC, therefore, this product most closely resembles the envisioned smart shoe design. However, currently, GaitUp's products are aimed at health professionals, and not the elderly user. Removing this 'middleman', the physician or GP, the focus of the product will shift towards the end-user. Certain design-aspects therefore need to change, greatly dependent on the target group's needs and wishes. Research into these needs and feelings towards mobility and falls is therefore of great importance. Hence, a focus group and contextmapping session is organized.

3.2 The target group

Now that the aim is to 'take out the middleman', as is portrayed in PhysioGait's product from Chapter 3.2.3, the end-user becomes even more important. In order for a person to change his/her way of walking, the product must be designed in specific ways, to connect to the target audience. However, how do you design for the elderly population and what does the target group actually want? In order to find out, and to get to know more about the elderly's needs and wants, a focus group was organized.

3.2.1 Autonomous ageing

In Chapter 1.1.4 it was stated that the Dutch population is gradually ageing, contributing to the challenge of falls prevention. This outcome is one among many other examples of functional decline, as ageing is a multidimensional process of change in the physical, mental and social domain. Design thinking has embraced ageing as a topic where it can add to public health interventions. Applications of design and technology can contribute to 'autonomous ageing', which aids independent living and supports the elderly's lifestyle (Van der Cammen et al., 2017). These applications might be able to compensate for functional shortcomings associated with ageing.

When aiding the elderly's lifestyles with technological products, these technologies need to be personalized for their needs, capabilities and preferences. They need to be designed with care, made familiar, usable, desirable, cost-effective and able to be adapted to the elderly's lives. This focus on supporting and reinforcing the reduced capacities of the elderly population by applying innovative inclusive design methods is very fitting to this project. Therefore, such a user-centered approach will be applied here in this phase.

3.2.2 Focus group sessions

Consequently, in order to know how this technological falls prevention product can be made most usable and desirable by the elderly, insights from the target group need to be gained. Their needs, wants and feelings are obtained by organizing a focus group and small contextmapping session.
The goal of the session is to gain insights on the seniors' feelings towards the topic of mobility, falls and wearable technology. The seniors' preferred way of being coached is questioned as well, as the elderly need to change their walking behaviour, meaning, lifting their feet higher when walking.

Procedure

The focus group is an approach which provides a quick overview of the target group's opinions about a specific topic. This method was chosen and combined with the general setup of the contextmapping method, in which designers use people's everyday lives to inform and inspire themselves for ideation. Therefore, contextmapping is a user-centered design approach in which users and designers work together on the

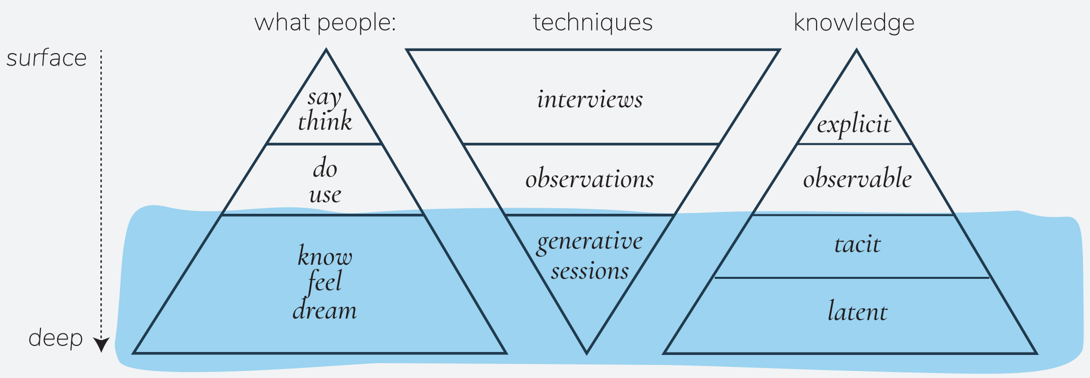


Figure 3.12: Methods that study what people say do and know help access different levels of knowledge as presented in the Convivial Toolbox (Sanders et al., 2012).

Figures 3.13 and 3.14: An impression of the two focus groups.

basis of expertise: designers are experts of the innovation process, whereas users are experts of their own experience. To get down to the elderly's 'core' feelings regarding ageing and mobility, generative sessions are conducted through the use of cultural probes. By doing so, this 'silent' or tacit, and latent knowledge, that people do have but which is difficult to express, or of which they are not aware, is addressed (Sanders et al., 2012), see figure 3.12.

With these generative exercises, the goal was to gain different layers of insights to use in the pre-concept stage of the project, to find new opportunities. In this way, the study would help to understand the users' perspectives and to translate the users' experiences into a desirable design solution. Apart from this eventual goal, it was also used to improve upon in-between outcomes, such as 'personas' and the 'interaction vision'.

Two focus group sessions were organized with a subset from the target group, see impression in Figures 3.13, 3.14 and 3.18, 3.19. Both sessions included four seniors aged between 60 and 75, the same age-range as the establisehd target audience, due to the technological threshold, see Chapter 5.1. Beforehand, an email sent out explained the aim and setup of the research, so that the participants knew what to expect, see Appendix A5. All participants were given sensitizing materials a week prior to the planned focus group, to initiate their thought process on the topics that were going to be discussed.

Cultural probes

The contextmapping session's preliminary work consists of preparation and sensitizing, as can be seen in Figure 3.16 (Sleeswijk Visser et al., 2005). In order to sensitize participants before joining a contextmapping session, various methods can be used. For this project it was chosen to use the Cultural Probe method (Delft Design Guide, 2016).

The participants were provided with a 'Cultural Probe package' which consisted of a little workbook, three sheets of stickers and numerous coloured pens, see Figure 3.15. The aim of these homework activities was to sensitize the participants to the topic of 'independent mobility'. By filling in the booklet, it helps participants to observe their own lives and reflect on their experiences and thoughts around the topic of mobility, needing help therein and the idea of a walking coach. After being warmed-up to the topic like so, the contextmapping session will be off to a good start.

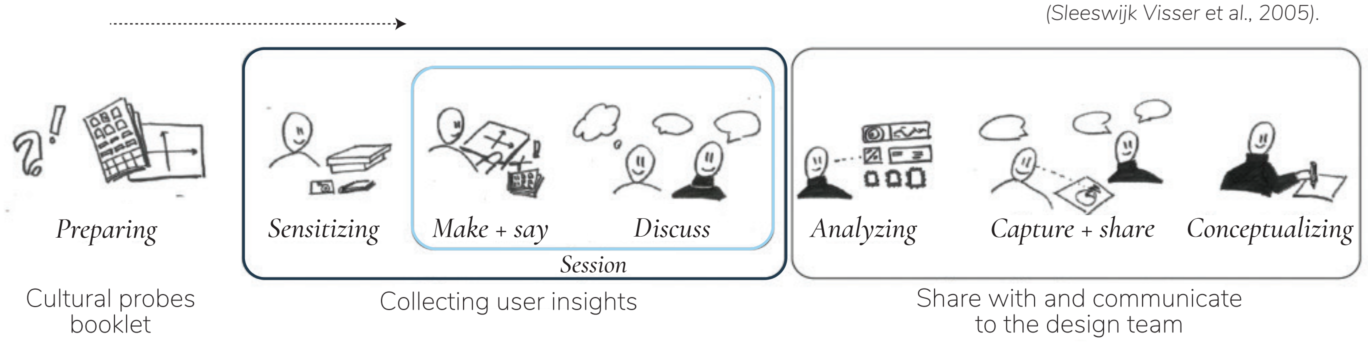
The order of exercises in the booklet was designed in a way to funnel towards the most important question, with all previous questions leading up towards this main question: 'If you could design your ideal walking-coach, what would it look like?'. The booklet can be found in Appendix A6.

Figures 3.15: The cultural probes package includes the designed booklet, stickers and pens. This was sent out to all eight participants.

3.2.3 Setup

In a focus group, participants meet in small groups to do generative exercises and talk about their specific feelings towards a topic and everything surrounding it. To ensure a productive session, a junior designer who finished the elective Creative Facilitation during his IDE studies, was asked to handle the task of facilitating the two planned sessions. The moderator has a vital role, for which experience with moderating or facilitating such a session is very helpful. For this reason it was chosen to recruit a friend to handle this task, so that I could observe, take notes and slightly steer the conversation when necessary. Together with him, the same planning for the two sessions was set up, see 'Facilitator Guide' Appendix A7.

Figure 3.16: The procedure of a contextmapping session (Sleeswijk Visser et al., 2005).



Both sessions were held with four participants, all within the targeted age group of 60-75 (M=4, F=4). It was decided to try to recruit elderly people with various backgrounds in technology use, level of mobility and activity, to provide diverse answers and to represent the target group as well as possible. The eight participants were distributed among the two groups accordingly.

The first half of the session was dedicated to discussing the answers to the questions from the booklet and some of these questions were specifically aimed at individuals based on their answers. Namely, digital versions of the booklets were sent back a day before the focus group was planned, so that all answers could be examined, in order to correctly prepare the session. See Appendix A7 for the full setup of the focus group sessions.

After moving away from the topics of mobility, independent living and receiving aid, a discussion on falls was initiated after the break. Consequently, a rough concept of the designed falls prevention solution was introduced and the conversation steered towards a co-creation session-style on this idea. At this time, the concept was explained as a 'product that knows when you have to improve your way of walking to prevent a (future) fall. Insights gained on this topic can be found in Chapter 6.4.

The chapter presented here is dedicated to the elderly's feelings and opinions towards (autonomous) mobility, independence and falls, see Figure 3.17

3.2.4 Insights

This section details the insights gained on the topics of mobility, autonomy, falls and receiving aid, from the perspective of the target group. The themes portrayed in this subchapter are named in a way to best capture the overall meanings of the intention of the eight research participants, see Figure 3.17.

Ageing - maintaining a positive outlook

All participants expressed their positivity towards ageing, all that comes with it, and towards life in general. 'Why worry about things you can't control or change?', was the overall attitude towards ageing. In this way, all elderly seemed very down to earth and to only care about the matter of facts. Comparing themselves to their preceding generation, as well as to the millennials these days, they say they've had it easy in life. Putting things into perspective like this, is what characterizes them. Two of the respondents expressed their feelings as follows:

' With every setback it takes a little longer to charge your battery. But at some point it's charged again and you go for it. Life just goes on, but you get a little stronger every time.'

'As long as you can still do things, you should. Because if you don't for a longer period, it has probably been the last time you did it. I'm convinced of that.'

All this does not necessarily mean that the elderly are happy about getting older, as they do experience physical decline. Though, they take it as it is. Being confronted with a decline in abilities can be difficult and creates an increasing awareness about the changes happening to one's body, one female participant said. Adjusting to this new situation (over and over again) requires patience. However, all participants agreed that the quality of life is most important, and therefore some indicated that you have to try as much and as long as possible to remain healthy and happy, when you are still capable of doing so. When time is catching up on you, the best thing to do is accept and to adjust to the situation. As one participant stated:

'At some point, you know some things or actions are no longer possible, though, you do want to return to that level. You'll try with trial and error or through lots of time or by going to the physiotherapist. But we know exactly what we were able to do and it is difficult to adapt to what is still there. You just have to accept it and figure out what way is still possible.'

Also, the elderly indicated that they are being stigmatized and classified, and they do not want to give in to this prejudice. This topic of age discrimination was called up in both focus group sessions and it clearly struck a nerve for all.

'I am quite a fanatic motorcyclist. Last year, when I was in Norway, a group of young people saw my licence plate, and they asked, "Did you come all the way from the Netherlands?" They were looking at me funny: for me to do something like this at my age. You don't do that and you're too old for that, you're done; they seemed to think.'

'We have new neighbours living next to us, aged 24 and 27, who watch us from time to time. "What a bunch of elderly people live next to us." You can just feel them think that.'

Remaining autonomous and independent

Except for one participant, all elderly are retired and have an abundance of time. They value this freedom, as they can decide when they are going where and how. Nonetheless, they very much understand that this freedom can be taken away from them in a heartbeat. For instance, two participants explained how they experienced this setback first-hand and the effects that it had on them physically and emotionally.

'I have walked very badly for years due to extremely severe osteoarthritis in both knees. When I walked, I needed half the street to move forward; I looked like a waddling duck. Since I have full prostheses in both knees, I walk like a little goat again. I no longer have to use my whole body to move forward and the pain is completely gone. That mobility is extremely important, at least for me. It is your freedom.'

'I've had a long nasty period after I had a hernia. If you like sports and doing things like that, and then suddenly you can barely walk and have this killer pain... and it also took them a long time to find out what it was. This all was really the worst thing I've experienced in my life.'

Through this, it became evident that the research participants want to remain mobile, free and independent for as long as they are able. Later on in life, if they would need any tool or aid in order to preserve that freedom they would gladly accept it, as it enables them to keep the control in their own hands.

'The freedom to decide when and where you are going: that is very important to me. It's okay if you need an aiding product for that, preferably not of course, but it is a solution. People with a mobility scooter still have some sort of freedom.'

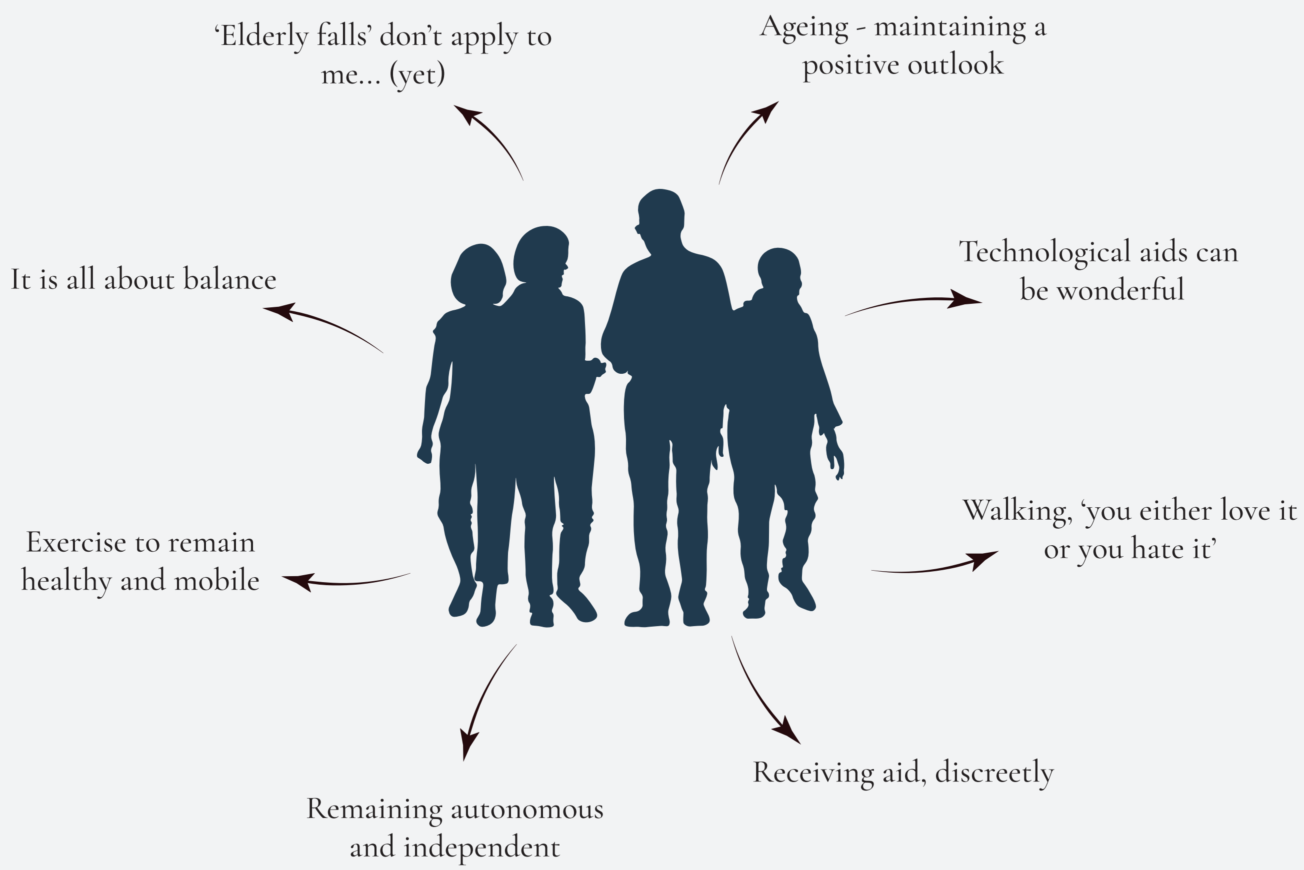


Figure 3.17: Overview of insights gained from the target group

Receiving aid, discreetly

For most respondents, preferably, such an aiding product [when discussing a possible signalling-product] has to be as invisible as possible. Though, when the product would be visible to others, it should be made attractive and stylish, 'not like those medical straps', or integrated in an existing accessory. In line with the topic of age discrimination, one female participant said the following:

'I want something attractive and stylish. Because, when you wear yet another wristband of some sort, others will ask: 'Gosh, what do you have there.'

Although, neither participants is currently using a walking aid, they do need help with small other tasks now and then. Asking others for help with this is difficult to some, as they don't want to admit that they need it. They don't want to be dependent on others due to the feelings of shame associated to it.

'I know that I cannot do certain things any more, such as lifting things. After some time, when I finally have the courage and ask for help, I also think: why did I get so nervous about that? People just want to help you, but you will quickly fill it in for someone else: 'Well, he is already busy or this and that.' Being dependent is the worst I think.'

Exercise to remain healthy and mobile

As mentioned earlier, all elderly indicated that they want to remain autonomous and independent for as long as possible, and that they are willing to work for that. When the respondents exercise, they say they do so mainly for this reason. They want to have control over their own future and outcome, and to postpone the possibility of ending up living on the windowsill at a retirement home. Therefore, the respondents keep in shape, though, to what degree differs per participant. Most say to do simple walks or exercises, while two male participants still go to the gym or out for a run once a week.

'When I go out for a run I do not take a mobile phone with me, since that's extra weight, but I do always wear an ID-copy on me. My wife tells me to do so, so that when I fall they'll [healthcare personnel] know who to contact.'

However, all indicate that they are open to engage in more exercise (routines) if a GP suggests this, as they are willing to put in time and effort to remain healthy. However, it must be possible to do this activity somewhat 'under the radar' and out of sight, due to embarrassment and privacy.

'In these times of corona, the people of the gym started exercising outside, right here in the middle of the roundabout. Then people no longer come, because then everyone is watching. That's what I mean by that threshold [falls-training outside], you don't do that.'

Also, the exercises need to be proven to work and easy enough to complete and, here again, they value the advice of professionals to coach them in this direction. Knowledge and, especially, stimulation coming from a physician or general practitioner proves to be of high importance, since it seems to be the right and only person they trust with their progress. As the participant who had both his knees replaced said:

'I also had to learn to improve my walk, because it [the osteoarthritis] also greatly affects your hips and your shoulders. The physiotherapist helped me a lot with it. I also had a lot of confidence in him, he was straightforward and honest with me from the start.'

It is all about balance

One metaphor that was used often throughout the sessions, which was also portrayed by the heavy use of the 'scale'-sticker throughout the sensitizing booklets, was the word 'balance'. This represented multiple things and was a recurring word when going through the various topics. The sticker was used on the front page of the booklet, by one of the female participants, describing the meaning of mobility to her:

'I have to weigh everything up if I want to achieve something. I mean, to get off the starting blocks when a new day begins. I'm often looking for a balance: when things start to decline, where do you put your focus? What is still salvable?'

On the topic of exercising in order to stay healthy, one of the male participants said the following:

'You do think you should exercise more, and you should do less this and less that. But you just bump on through. Until one day something bad happens to a family member or a friend. Then that switch flips for a week or two and you try your best, though you slowly forget it again. The next thing you know, the good intentions are gone and the pint is back on the table.'

It is therefore clear that, as many things in life, elderly weigh up certain things when making a decision or when tackling a problem. On the topic. When possible problems are not a matter of day now, but you do know that they could be waiting for later, you would have to be quite dedicated and have plenty of willpower to already start doing something about it now, one says. However, with all that is healthy and 'good', there are tempting opposites too.

'You don't want to do too much [exercise or eat healthy], because you also think 'seize the day'.'

Walking, you either love it or you hate it

A theme on which opinions were largely divided was the topic of walking. Half of the participants indicated that the activity of walking is a hobby to them. A moment of reflection, a time to let your thoughts go or to calm yourself down. They see it as an outlet, a moment to come back to your senses.

Walking is one of my biggest hobbies, I have been walking a lot for several years now, I also participate in large hikes. When I was still working I actually walked even more than I do now. I had a busy job, which was quite stressful. In the evenings I would go out for a walk and my head would be emptied again. When walking, you can process your thoughts and give more and better meaning to it. That's what I mean by walking: peace.'

However, for the other respondents, walking is merely a practical thing; they only walk to cover small distances, do grocery shopping or to post something. Even so, one male participant admitted doing the latter by bike, even though his mailbox is <100 m away. Walking is too slow for him, admitting hating it.

'I don't like walking, no, it is all too slow for me. At work, I often hear "Come, join us for a walk", but I always want to go back to the office after 100 m. I really love cycling, though.'

The participants indicated that they spend more time on preparation whenever they go out for a (longer) walk. The walking route and the type of footwear or walking-ground have all become more important, now that they are getting older and more fragile.

'When I walk, I prefer to walk on the bike path rather than on the sidewalk. The bike path is often paved, while the sidewalk often sticks out in all different directions.'

'I recently bought cheap shoes and I really felt everything. Immediately thrown in the trash.'

'Elderly falls' don't apply to me... (yet)

When steering the conversation towards falls among elderly, feelings towards this topic were in line with: 'But we're not really that old yet'. Especially the younger research participants had this response:

'Because you do associate it [falls] with aging and a certain age, and I don't have that [age] yet. "I still belong to the younger generation", you think. But of course, that is not really true is it?'

However, some admitted to, perhaps subconsciously, acknowledge the impending risk of a fall more and more.

'I assess situations quite often: I might just fall there. I pay a lot of attention to this, especially in unknown environments.'

Gladly, not many participants had experienced an 'elderly-fall', except for one female participant.

'I was walking my dogs along the beach road and I suddenly clattered down, it happened very quickly. I thought: What's this now? I just suddenly fell like a log, flat with my face on the sidewalk. Usually you have this reflex, to try and grab something, but that was not possible.'

When changing the topic to education on falls and fall-training for elderly, one respondent who also highly recommended it to the rest of the group said:

'I am fortunate that I used to practice judo when I was younger, which included some excellent fall training. I can therefore handle myself reasonably well, when I make a stumble. At this age, you notice that we are no longer as smooth as we were 40 years ago, the act of falling is way different now.'

However, spending time on this already feels quite unnecessary to them, as they feel they are not that old yet and it is something to look at or worry about in a couple of years, perhaps. Yet, somewhere inside they do know that they could improve their health a little in order to possibly postpone that (first) 'elderly fall'.

'You have to fall first, I think, only then you see the need for it [preventative exercises]. Only then you get to work, when it becomes a necessity.'

Also, all elderly agreed that there needs to be more education on the topic of falls and that its consequences must be made more apparent to the elderly population. As there's a threshold to go out and look for something like fall training yourself, since falls and ageing is a taboo subject, the respondents feel like it could be advertised more and made more accessible and common.

Technological aids can be wonderful

When talking about general health, many indicate to know their body well. They trust what they feel and what their body tells them: when something is wrong, they'll know. When that happens, neither of them indicated to search for symptoms online, consulting the internet can be misleading. They value the advice of the general practitioner, and making real-life appointments with professionals.

'I then [after an online search] thought: I should never do this again. I have complete confidence in the doctor and in my own body. I will never search for diseases or anything online again.'

However, the technology they do like and are amazed by, are all the improvements in useful technological gadgets happening in recent years. Half of the group is very much aware of these technological advancements and are quite impressed by them:

'I sometimes see those glasses that have technology implemented in the temples, allowing you to give commands with your voice; I love that you can do things like that with technology nowadays.'

'A neighbour down the street, I don't know what kind of illness she has, cannot get out of bed independently, but she has a robot that helps her with that. That robot helps her get up every morning and I think that's absolutely wonderful.'

If things start to deteriorate more, with regard to mobility, all elderly are open to try such a technological product or tool that can help them and give them nice tips. As stated before, most elderly feel like they are not really at risk of a fall any time soon themselves. The incentive for them to already start working on 'postponing the next fall' is therefore a difficult matter. A product or exercise routine that could convince them must be easy to act out, show (fast) results and stimulate them in getting off the couch.

'Well, if something like that [an aiding product] was introduced to the market, though I don't think about it [falls] now or the consequences, and you read things about that it really helps people... Maybe you will actually use it, yes, those tips and exercises or tools. That you realize by reading those stories then, that can happen to me too. But not now. I'm not yet concerned about any of this now.'

Figures 3.18 and 3.19: An impression of the two focus groups.

3.2.5 Summary of insights

Overall, the participants are quite positive towards ageing, as well as to remaining autonomous and mobile, and they do not resist using equipment or technology in order to stay this way. They are open for suggestions on how they could improve their health and mobility, as long as those suggestions are made by an expert and the threshold is low enough for them to partake in any exercises i.e.

The elderly quite like the sort of equipment that this project revolves around, as they are intrigued by the technological advancements that have happened in the past years. However, they admit to wanting

Big differences can be found in feelings towards walking, as some love it and view it as their hobby, while others find it too slow and a too much of an effort. Therefore, the gradations in what way the participants would like to stay fit and to maintain a healthy gait, in order to postpone a fall, also vary quite a bit. Some would like to do simple exercises; like balancing on one leg while brushing their teeth, while others want to gain exact insights in their way of walking and how to optimize their gait. These wishes of the somewhat more active and less active elderly need to be looked after in design process.

The insights derived from the focus group sessions are translated in distinct user needs, presented Chapter 4.3.

Limitations

Due to the age of the participating elderly being at the low end of the spectrum, with regard to the target audience, they indicated to not being that concerned with the topic of falls yet. The insights gained show this as they feel that they are not experiencing the problem (yet). Therefore, in future studies, a bigger subset and a more diverse age-range should be used to gain more in-depth insights.

3.3 Expert knowledge

Besides gaining insights from the target group, it is also important to listen to experts from within the field of geriatrics and falls prevention, to be able to better match the product to the context of the current medical care. In order to do so, two interviews were set up to gain input about issues regarding the complex strategies on falls prevention and current advancements. The general product-idea of the smart shoe analysing the MTC parameter was presented, to hear the experts' thoughts.

In Chapter 3.1 it was concluded that GaitUp's product, the Physilog, is the product that comes closest to what I'm striving for in this project. However, as that product is designed for medical professionals, and not the elderly, this end-user-focus will shift in my design. Nevertheless, the medical care professionals will not be left out, as their expertise is highly important, further detailed in Chapter 6.4. They will be part of the design and therefore their input is desirable. The two specialists interviewed are Prof. dr. Nathalie van der Velde and Dr. Shanty Sterke, through conducting two separate interviews online. This subchapter presents the two summaries of these interviews, the themes portrayed are named in a way to best capture the overall insights gained. The full transcripts of the two interviews can be found in Appendices A8, A9.

3.3.1 Interview with Prof. dr. Nathalie van der Velde

Prof. van der Velde is a researcher and professor in Geriatric Medicine at Amsterdam UMC with a special focus on falls prevention in older people. She supervises a Fall Clinic, where she coordinates the medical knowledge. Alongside this, she is active in the context of knowledge dissemination and implementation. Namely, Prof. van der Velde is Committee Chair of the National Network of Falls Clinics and organiser of the annual National Fall-Symposium.

Striving for personalized treatments

Prof. van der Velde affirms that the prevention of falls is an issue which is multifactorially determined. As was concluded in Chapter 1.1.3, there are many risk factors for falls. Therefore, when assessing an elderly faller, she indicates that it is of high importance to look broadly to all possible causes. She says that for the most part, it is fairly unknown how specific risk factors and causes coexist and why some factors have (more) effect on certain individuals than others. Therefore, to be on the safe side, falls prevention approaches can be largely characterized as 'one size fits all-solutions', covering numerous risks at once. However, Prof. van der Velde aspires for more personalized advice:

'We know that certain (prescription) drugs increase the risk of falling, but not everyone falls when taking this drug. Therefore, we are trying to figure out which individuals are likely to fall due to this medicine, and who will not, enabling us to give individual advices.'

Capturing the moment before an individual falls is tricky

The objective of being able to give every patient a more tailor-made consultation has also been researched in the field of gait analysis. On the topic of wearables intended for (instant) fall risk analysis and feedback, Prof. dr. van der Velde confirms what was concluded in Chapter 3.1.4: a lot is being researched and published in this field. She indicates that it has proven to be rather difficult, as wearables can say something about the gait patterns at group level, though, analysing whether an individual will fall at a specific moment is very complicated. This is due to the different characteristics in gait patterns and walks that people have. There might not be 'one rule' that can be applied to every single individual.

The MTC might open up new possibilities

On the other hand, Prof. van der Velde expressed her strong interest in the focus of the MTC, as she was not aware of any research into this topic. As she, also, indicates that this parameter is highly correlated to a shuffling gait, she recognizes its high potential.

'I've never heard anything about that toe height, I don't know anything about it from my fall-research, but I find it quite fascinating!'

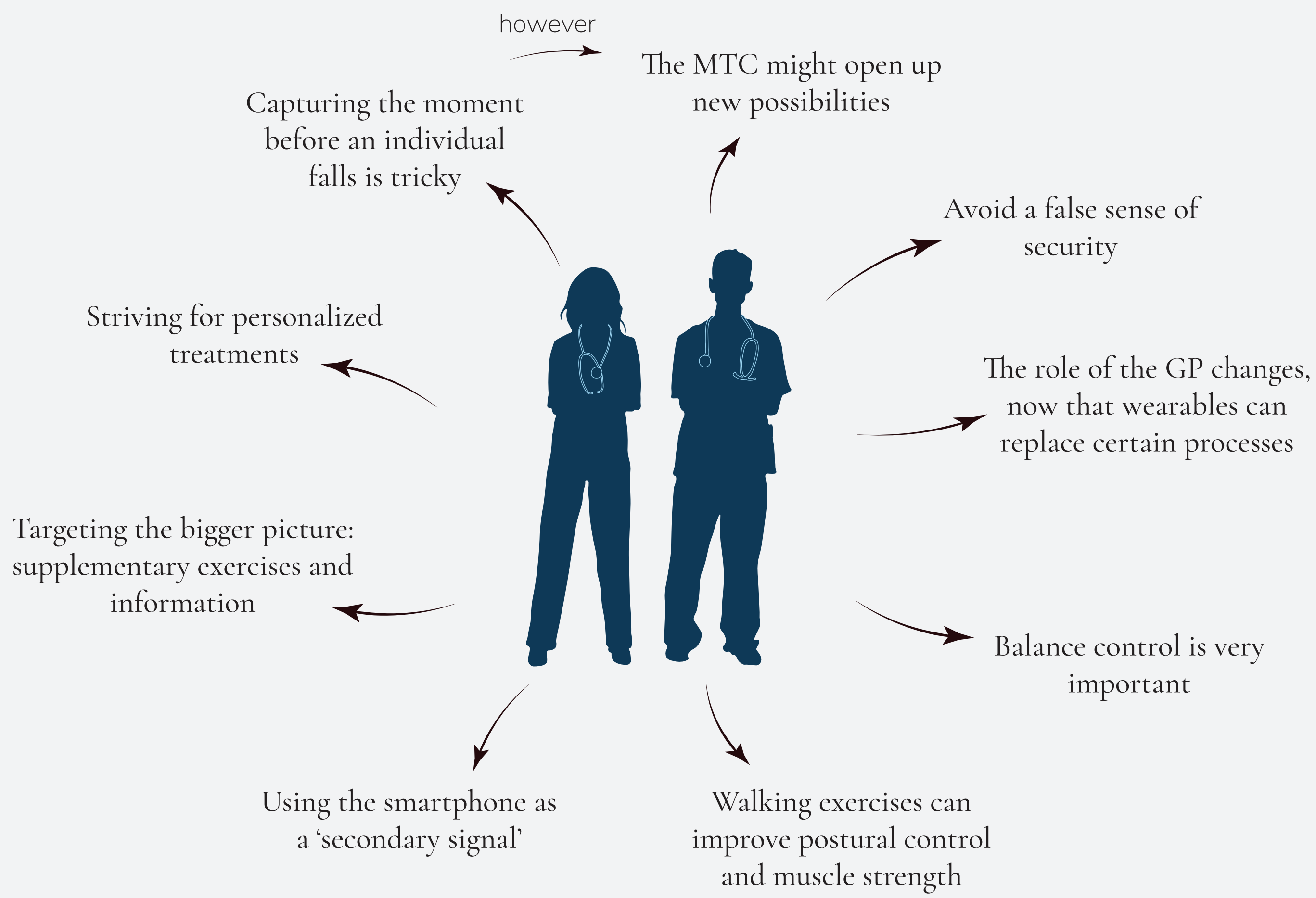


Figure 3.20: Overview of insights gained from the two healthcare professionals.

Targeting the bigger picture: supplementary exercises and information

An intervention tageting the MTC is not enough, Prof. van der Velde says. This focus on the MTC should be supported with concrete advice on sufficient and safe exercise to improve the MTC. In this way, looking after the bigger picture: aiding the improvement of the gait, optimizing the MTC parameters, with the right knowledge and training. Information should be provided on how much and how intensively one should move, prescribing a balanced and well-thought-out 'training schedule'.

'If you have a shoe that just says "Stop shuffling": it's not going to be enough. If you really want to accomplish falls prevention, you have to do more than just putting an end to shuffling in itself.'

Prof. van der Velde pointed out the importance of these accessory elements, as well as accessory feedback. The elderly are in need of this information. Not only at the moment of the intervention itself (the 'Stop shuffling. - signal), but also afterwards, as a way for the elderly to gain knowledge on how to limit the occurrence of this first signal. This requires a so-called primary and secondary signal. This primary signal should not scare the elderly, as by way of an unexpected signal, people can actually fall at that instant. This would go completely against the purpose of the product.

Avoid a false sense of security

Prof. van der Velde expressed her concerns on the product's focus of one particular gait variable, as it could give the elderly a false sense of security. When providing direct feedback on one's gait patterns, this feedback should be made complete. Picking out just one element will not prevent falls, preferably all the elements that matter to falls prevention and mobility issues must be incorporated into the product somehow.

3.3.2 Interview with Dr. C. S. (Shanty) Sterke

After studying Movement Sciences, Dr. Sterke obtained a PhD on a study on falls in the nursing home. She now works as a science journalist and researcher, studying the values of physiotherapy in long-term care. Additionally, she works in physiotherapy department in a nursing home.

Balance control is very important

In line with the risk of a false sense of security when solely focusing on one parameter, Dr. Sterke indicated that (a sudden) variability in one's gait pattern is most characterizing for a future fall. Her research made this conclusion from when they were researching the relationship between fluctuating gait parameters and falls. It is therefore important to register changes in gait parameters over a somewhat long(er) period of time, to see this variability happening.

'In an article I read, elderly people in a nursing home were carrying a sensor. Another sensor put up in the hallway was able to analyse their gait patterns. When the product would notice more variability in an elderly's gait, then that person would actually fall shortly thereafter. Indicating that something was off, an underlying disease or illness perhaps.'

Dr. Sterke and her research team noticed that variability in step width increased with age for non-fallers, eliminating it as a predictive parameter for falls. It could explain the non-fallers' better sense of balance control, as they were more capable of correcting their balance by stepping out, and hence, perhaps prevent a possible fall. Therefore, stance or step width does not have to be included in the product's analysis.

Walking exercises can improve postural control and muscle strength

Besides a possible impaired balance control for elderly that showcase overall gait variability, Dr. Sterke says, if someone is less able to lift their feet, it is a good indication of possible muscle strength loss. Through balance- and walking exercises, both these physical types of decline can be trained and maintained. In fact, Dr. Sterke says that walking releases a chain of favours, as it improves one's condition, immune system and also one's muscle strength. She adds: when someone gets a signal that they have to raise their feet a little higher, that person is already doing some sort of muscle exercise.

'Whatever ailment someone has, the remedy is almost always: move more or more intensively. Regarding the elderly, it is almost always a mobility intervention.'

Using the smartphone as a 'secondary signal'

Dr. Sterke agrees with Prof. van der Velde that extra information must be given to the elderly on how to execute the walking- and balance exercises, to enable the patient to enhance their gait themselves, rather than the sole signal of 'Lift your feet!' An app providing this additional information might work as the 'secondary signal', Dr. Sterke thinks, as she's aware that more and more elderly have smartphones.

'I think, indeed, that an App has the greatest potential. People usually also get instructions and help from children or grandchildren to make it work, so I do see that happening yes.'

Dr. Sterke adds that, besides reminders to exercise and other notifications, positive feedback would work well for the elderly as well, as it keeps them more motivated.

The role of the GP changes, now that wearables can replace certain processes

The current trend in healthcare is that people really have to get to work themselves, and not receive endless therapy. Older patients will be given some exercises to do at home and the GP generally checks up with them two weeks later or so. Now that wearables have become more accessible for everybody to use, older people often have a smartphone. Dr. Sterke indicates that she has been using this wearable health technology more often to optimize her elderly care. Through the help of the pedometer-function, she checks whether the elderly have been walking regularly, how intensely and other important performance details.

'The objective feedback I can extract from the pedometer is very valuable, as I can discuss it with them [the elderly patients]. This works really well. If your product could to this in regard to those other gait parameters, it would be really interesting!'

3.3.3 Summary of insights

A visual summary of all insights gianed can be found in Figure 3.20. Both experts agree that analysing the MTC by a wearable device is very interesting and shows great potential as a falls prevention tool, as long as it is designed correctly. Most importantly, this means that the intervention or primary signal saying 'Lift your feet' should not scare the elderly, as this could potentially backfire and lead to the matter we're trying to prevent: a fall.

Also, the design should keep both the elderly population and the experts treating these patients in mind, as both are stakeholders in this matter. Additionally, preferably, the analysis of as many elements that matter to falls prevention and mobility issues must be incorporated into the product, as a sole focus and optimization of just one parameter could lead to a false sense of security. The focus on the MTC should therefore be supported with analyses on multiple gait parameters and concrete advice on safe exercises to improve the MTC, and other measures.

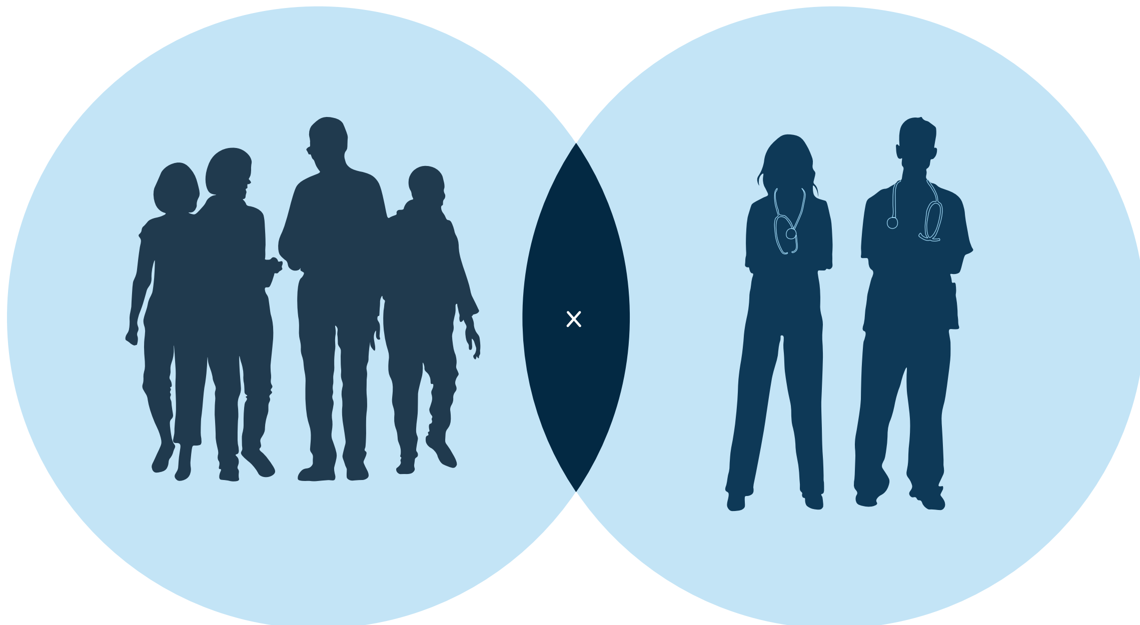
This 'self-help' information and education on how to train, the so-called 'secondary signal', should be presented to the elderly user by means of an app. As Dr Sterke has seen, an increasing number of (younger) elderly people have smartphones or fitness trackers, therefore this will not be an issue.

Finally, experts who might be interested in giving more personalized advice to their patients include geriatricians, GPs, physical therapists, physicians or nurses. It could therefore be concluded that such a product that could provide these experts with objective feedback regarding their patients' ailments would probably be very welcome to all. Like so, with the introduction of the product, it would create a 24/7 'mobility-coach' for the elderly and output more and more objective data on the elderly's performances, with which the experts can improve their consultations.

3.3.4 Solution space

Insights from both the target group as well as from the geriatric healthcare professionals have been gained, see Figures 3.17 and 3.20. The solution space lies in combining all needs, requirements and wishes into a product that is designed with care, is usable, desirable and cost-effective, able to be adapted to the elderly's lives and most of all, safe to use while aiding falls prevention, see Figure 3.21.

Figure 3.21: The solution space.



3.4 Persuasive design

As this projects focuses on falls prevention through the analysis of mobility patterns and gait and postural imbalance, the focus will be on the fall risk factors which are 'biologically modifiable'. Namely, those prone to be targeted for behavioural change. Since the eventual product will address a specific shortcoming in one's gait to, eventually, reduce the risk of a fall, it comes down to the individual's commitment to change this specific pattern, or habit. In order to achieve this, it is valuable to gain insight into how to persuade people towards changing their behaviour.

3.4.1 Behavioural change

The eventual product should turn the elderly user's suboptimal gait into a healthier one. In order to achieve this, the elderly need to put effort into slightly changing their way of walking. It is therefore important to understand existing theories about behavioural change, as they can help in nudging the user to the correct behaviour. The Behavior Model for Persuasive Design, by Fogg (2009) will therefore be discussed in this subchapter.

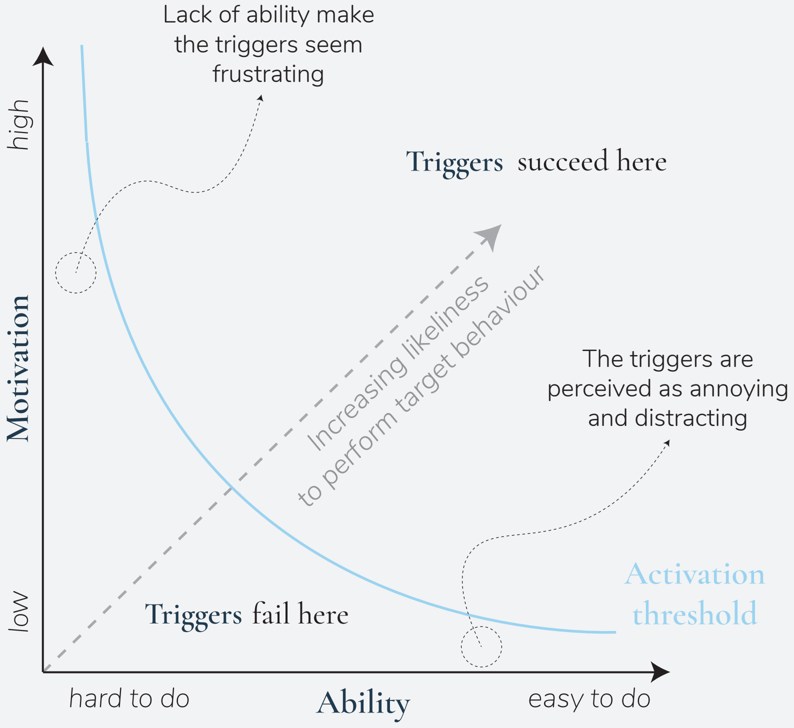
3.4.2 Fogg's Behavioral Model

Fogg's Model (2009) shows that a behaviour is a product of three factors: for a person to perform a sought-after behaviour, he or she must (1) be sufficiently **motivated**, (2) have the **ability** to perform the behaviour, and (3) be **triggered** to perform the behaviour. These three factors must exist at the same time for the behaviour to happen. Designers should therefore offer sufficient motivation, sufficient ability and an effective trigger in their product/service, for an accessory target behaviour to happen.

In this model, see Figure 3.22 to the right, the first two factors (1) Motivation and (2) Ability are placed on the two axes, and they can be traded off: as when motivation is high, ability can be low, and vice versa. Motivation and ability therefore have a compensatory relationship to each other, the activation threshold, illustrated by the curved orange line. For example, when someone has a low motivation to do something, but it is very simple to do, he or she will be likely to take action.

Being highly motivated to do something, he or she will find ways to do it anyway, whether it is hard or not, and you can get people to do hard things. When a combination of motivation and ability places a person above the activation threshold, a trigger will cause that person to perform the target behaviour.

Figure 3.22: the Fogg Behavior Model (2009)



A. Motivation

The first factor of Fogg's behavioural model is motivation. It is quite unlikely for someone to change his behaviour when feeling unmotivated, therefore the goal in designing for motivation is, conceptually, to move the user to a higher position on this axis. In his framework, Fogg describes that motivation comes in three different shapes: the core motivators. These motivators apply to everyone, they are central to the human experience. Each of these motivators has two sides, as can be seen in Figure 3.23.

Sensation: Pleasure / Pain; The result of this core motivator is immediate, or nearly so, as there's little thinking or anticipating. This is a result of a primitive response, functioning in activities related to self-preservation, like hunger.

Anticipation: Hope / Fear; This core motivator is characterized by anticipation of an outcome being either good or bad, which translates in either hope or fear. This dimension is at times more powerful than the previous, as this core motivator is evidenced in everyday behaviour. For example, people are motivated by hope when they join a dating website, though, motivated by fear when they update settings in virus software.

Belonging: Social acceptance / Rejection; Belonging controls much of our social behaviour, as people are motivated to do things that wins them social acceptance or that avoids social rejection. The power of social motivation is hardwired into our brains, as all creatures are historically dependent on living in groups to survive.

When you are seeking to boost levels of motivation as a researcher or designer, you can look into how these dimensions can be embodied in a product. As the *anticipation motivator* is probably the most ethical and empowering, the focus will be laid here. Additionally, this motivator fits the fear of a potential fall best, or the 'rest-product' of this event: the fear of loss of one's mobility or independence.

Though, the eventual product's design should also reckon with the other two motivators, to ensure the highest level of motivation and longest period of utilization by the user. The *sensation motivator* is characterized by the prospect of pain. This motivator can especially be used on the elderly people who have experienced a fall before, and its negative consequences.

Additionally, the design and placement of the wearable should be nonintrusive to safeguard the elderly's needs to not be stigmatized as an elderly, see Chapter 3.2.4. This greatly falls in line with the social rejection aspect of the **belonging motivator**.

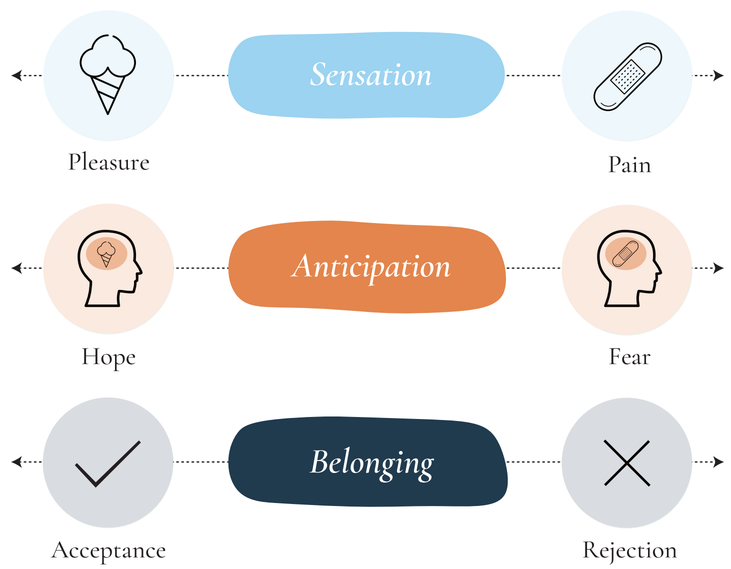
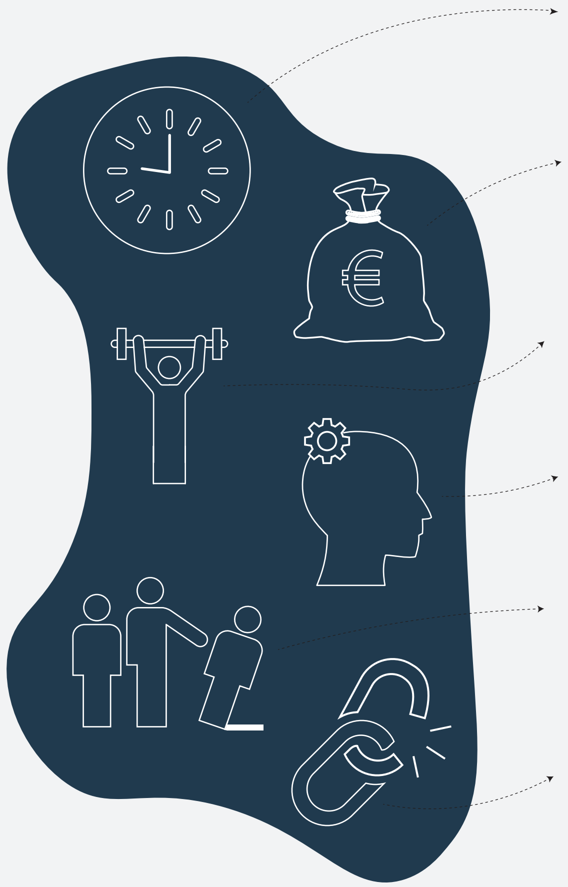


Figure 3.23: The three core motivators

B. Ability (or Simplicity)
The second factor is ability, or simplicity, and it describes how easy it is for someone to take action. Namely, in order for a person to perform a target behaviour, he or she must have the ability to do so. In his framework, Fogg (2009) mentions that there are six different elements that together shape ability. These six elements related to each other like links in a chain; all need to be present in order for a user to take action.



Time; If the target behaviour requires time and the person doesn't have time available, the behaviour is not simple.

Money; For people with limited financial resources, a target behaviour that costs money is not simple.

Physical effort; Behaviours that require physical effort may not be simple (for everyone) to execute.

Brain cycles; If performing a target behaviour causes one to think hard or differently from what they're used to, that might not be simple.

Social deviance; If a target behaviour asks one to go against the norm or break the rules of society, that behaviour is no longer simple.

Non-routine; People tend to find behaviours simple if they are routine: activities they do over and over again. When one faces a behaviour that is new / not routine, they may not find it simple.

Figure 3.24: The six different elements that shape 'Ability'.

Every individual has a different 'ability profile' and therefore the six elements vary per individual, though, they also vary by the context. When one misses out on one element, due to circumstances (finding out you forgot your wallet when already in the supermarket), the behaviour of buying products is no longer easy to perform. Fogg indicates that ability, or simplicity, is a function of a person's scarcest resource at the moment a behaviour is triggered. Therefore, ability describes how easy it is for someone to take action, measured at the moment a trigger occurs.

As researchers and designers, we should seek to find what resource is scarcest for our audience: time, money, the ability to think? When discovered, barriers for performing a target behaviour can be reduced. Optimizing this factor can move users across the behaviour activation threshold.

Also, when creating persuasive technologies, you should remember that what's simple for one person is not always simple for another.

C. Triggers
The third and final factor of Fogg's framework is triggers, or the term more frequently used in the design world: call to action. A trigger is something that tells people to perform a specific target behaviour now. For behaviours where people are already above the activation threshold (in the grey shaded area, see Figure 3.25), a trigger is all that is required. According to Fogg, there are three types of triggers (2009).

A spark is a trigger that motivates behaviour (high ability, low motivation).
A facilitator is a trigger that makes behaviour easier (high motivation, low ability).
A signal is a trigger that indicates or reminds (high ability, high motivation).

With technology becoming more and more present in everyday life, the role of triggers has grown in importance. When using interactive technology, one can receive a trigger and perform the target behaviour immediately. This interactive trigger will be the main part and focus of the to be designed product. With a specific trigger the walking behaviour of the elderly user needs to be optimized, every time when incorrect behaviour is detected: incorrect lifting of the feet.

As the aim of the product is changing the walking behaviour of the user, which has a relatively low threshold, you could say that the ability to perform this action is high, it is easy to do for most individuals.

Though, the motivation to partake in this change daily is low. Therefore, the trigger to be designed will most likely be in the shape of a spark, focusing on motivating behaviour.

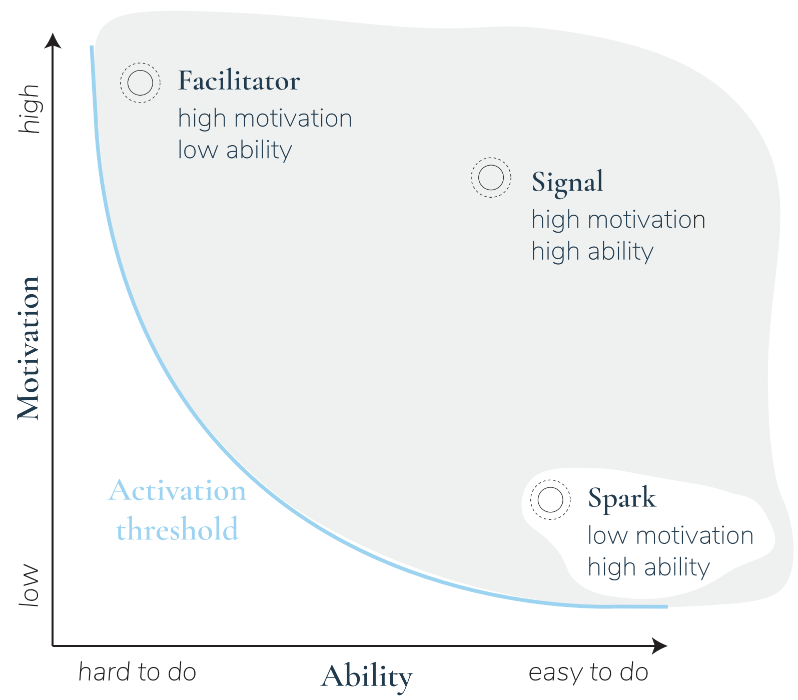


Figure 3.25: The three types of triggers and their position in Fogg's model.

3.4.3 Using Fogg's model

For this project, in order for the elderly to adopt a more healthy and optimized gait pattern, all three factors of Fogg's model need to be incorporated and reflected in the final product design.

Through conducting the focus group sessions, it was concluded that some elderly may want the product to solely motivate them to optimize their gait through the MTC parameter, and need the displayed information to be as compact as possible. However, others might wish this focus to be supported with more elaborate balance training and exercises, to improve their gait and vitality in general. Here, a distinction in the more inactive and active elderly could be made. These envisioned differences in potential users are shown through the use of personas in Chapter 4.4.

Additionally, as mentioned before, every individual has a different 'ability profile' and some elderly might be more able and capable to partake in change than others.

Consequently, the magnitude of both these first two elements varies, and therefore the user needs-insights should be handled with care.

As a rather indisputable given, people are most tolerant of triggers when they are being represented as signals or facilitators. The triggers 'sparks' may annoy too much, since they seek to motivate people into doing something they didn't intend to do. As the eventual design will revolve around the elderly being constantly reminded of improving their gait when a specific shortcoming is detected, this reminder-trigger will mostly reflect that of a spark: motivating them to walk correctly. This third element will be researched in detail in the following chapter, Chapter 3.5.

3.5 User adaptation

The literature research and immersion with the target group resulted into a design goal: 'Design of a concept that prevents falls among elderly (60-75), by real-time monitoring of the user's MTC variable and instant signalling of apparent risk therein, in addition, clarifying this through supportive education and exercises on a separate UI', see Chapter 5.1. In order to reach this goal, the user must be willing to adapt to the smart shoe and this requires commitment from the side of the user. This chapter will create the bridge between this desired context scenario, and its accessory interaction visions, and the resulting product functionalities. The outcome will provide guidelines on social factors that are important to reach the desired vision and goal.

Through the focus group sessions, it was found that it is hard for the participants to stay dedicated to change. Often this is related to factors influencing the experience of the user. If one element changes into something negative, the user could decide to quit.

In this project's design this is very important. If the overall concept contains one or more elements that are perceived as negative for the user, he or she will not use the smart shoes, (integrated) wearable and its accessory app. This means that 'user adaptation' is just as important as the correct functioning of the product. Namely, if no one wears it, the product is not capable of having any impact or evoking the result of fewer falls among the elderly.

3.5.1 User adaptation

One of the three factors leading to behavioural change is motivation, as is portrayed by Fogg's model in the previous chapter. Together with ability and triggers, they together nudge the user in a desired target behaviour, in this case optimizing their MTC levels. The latter two are factors that are already greatly reflected in the design, as the trigger is represented by the primary signal and the ability is largely reflected in the secondary signal. Namely, the behavioural change 'lifting one's feet a little higher during walking' by itself does not necessarily have a high ability-threshold. Moreover, the mobile application (secondary signal) can provide the user with clear information on how to adequately perform this behaviour, avoiding any ambiguities. As the third factor of motivation is not correctly reflected in the design yet, this should be explored more through focusing on user adaptation.

User adaptation requires ongoing commitment from the user, through correctly designing a product's or service's characteristics. By doing so, users are not only willing to adapt to a new behaviour, they remain committed over a longer period of time Buenaflor and Kim (2013). Hence, they stay motivated. This greatly overlaps when designing for desirability in the trifecta innovation framework, see Figure 3.26.

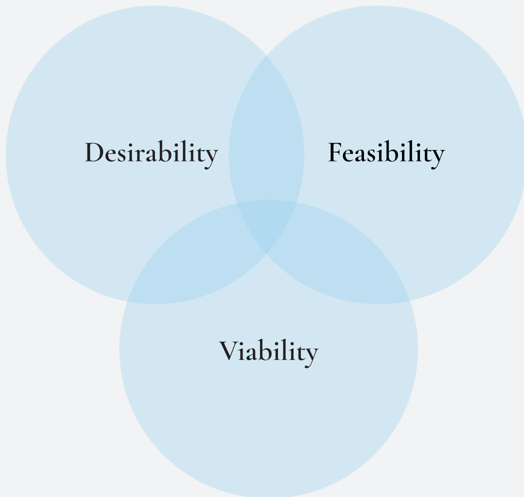


Figure 3.26: The innovation trifecta

3.5.2 Six factors for wearable adaptation

Research is conducted on how to design for motivation and keep users engaged when designing a technological wearable. Hence, making sure the eventual product matches the needs of the target group, ensuring sustained desirability. A research paper by Buenaflor and Kim (2013) is used to understand what determines the user adaptation for technological wearables. The researchers describe six factors affecting the acceptance of wearable devices, resulting from a review on previous human-centered studies in that area, displayed in Figure 3.27.

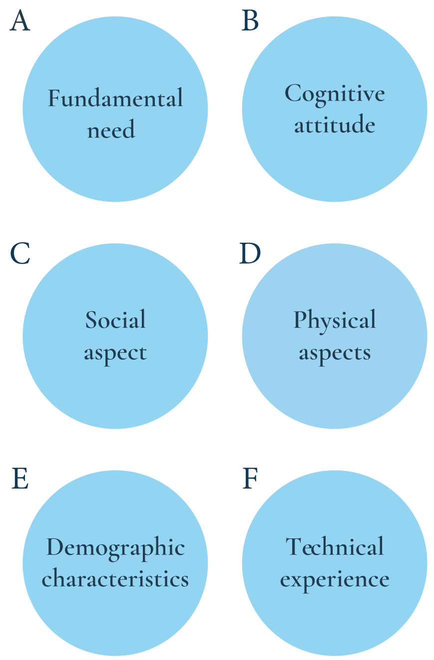


Figure 3.27: The six factors affecting the acceptance of wearable devices (Buenaflor and KIn, 2003)

A - Fundamental needs

Fundamental needs characterize the six hierarchical needs, as described by Maslow's pyramid, see Figure 3.28 (1958). Researchers evaluated the influence of these needs in a study about the relation to uses and features of smart textiles (Duval et al., 2010). The research showed that people are strongly attracted to smart clothing when they satisfy physiological needs, the lower two layers of the pyramid. Therefore, having elements of one of those two layers in the design, will increase the likeliness of user adaptation.

Ultimately, the smart shoes aim to prevent falls among the elderly. You can therefore state that people are already predominantly attracted to the product, as health is the second layer of Maslow's pyramid. Consequently, to make the target audience aware of this, this health aspect should clearly be represented in the design. As the user needs were built upon the hierarchy of needs, this first factor is greatly attended to.

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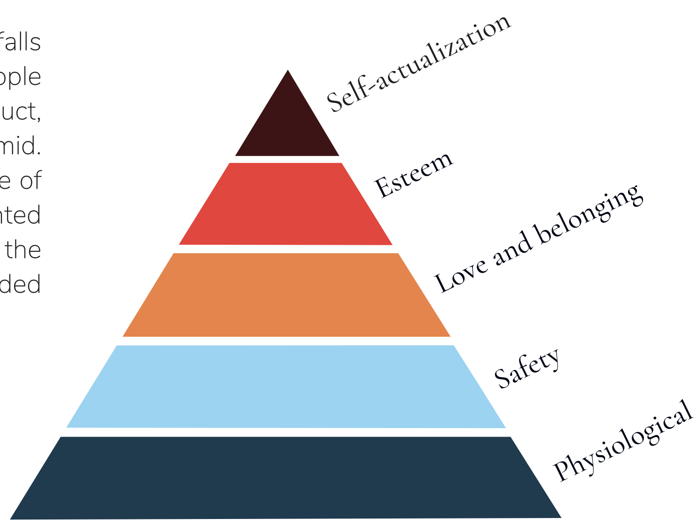


Figure 3.28: Maslow's hierarchy of needs.

B - Cognitive attitude

Buenaflor and Kim (2013) describe this second factor as acceptance of technology, for which they make use of the Technology Acceptance Model (Venkatesh and Davis, 2000), see Figure 3.29. This model is used to define user acceptance of newly introduced technologies, by focusing on two essential factors that affect the intention to use a technology:

Perceived usefulness

This relates to the perception of the user on how well the wearable device is capable of enhancing the performance of a certain task, or e.g. be an effective and practical solution to an existing problem. The focus group insights showed that independence is very valuable to the elderly people. The participants indicated they would consider using a system if it is deemed useful, reliable, and provides obvious benefits to their independent life, see Chapter 3.2 User needs.

Perceived ease of use

When a technology is easy to learn and operate, users will be more comfortable and confident in using it, thus it is more likely to be accepted (Buenaflor & Kim, 2013). A study on preferences of clinicians and patients with regard to body-worn sensor systems concluded that both groups emphasized the need for a simple-to-use device (Bergmann et al., 2011). If a device is perceived to be complicated and difficult to use, users tend to become anxious and worry about making mistakes that would cause harm to their body as the device is worn by or attached to them. This expected danger leads to lower confidence in using the device.

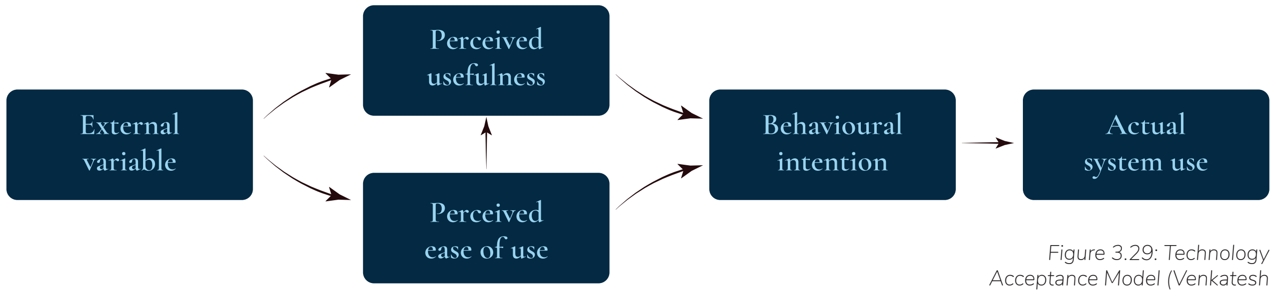


Figure 3.29: Technology Acceptance Model (Venkatesh and Davis, 2000).

C - Social aspect

Social aspects are related to social relationships and interactions that can influence how the user perceives or enjoys the product. Buenaflor and Kim (2013) describe three important factors:

Personal privacy

People are cautious in sharing personal data with others, especially if giving such information will bring potential harm to them in a social sense. Privacy is a critical issue, particularly in an environment of omnipresent and inescapable technology usage (Kurkovsky et al., 2008). According to Boscart et al., (2008) comfort and security in accessing and sharing data are crucial factors in the acceptability of a wearable device. Transparency of which data is being collected and what is done with it is essential. If this is ambiguous, people are more suspicious and cautious with sharing their data.

Social influences

People tend to value their relationships with those close to them and their opinions and beliefs. This is often a primary consideration in making decisions. In the context of technological wearables, this was demonstrated in a study on wearing smart clothing: women were less willing to use/wear the product if their social network or environment did not favour the technology (Kortuem et al., 1999). In the context of this project, for the panic alarm systems for elderly, e.g. Avium's Buddy Alarmknop, it is reported that some elderly people are ashamed of wearing these products and may reject the system to avoid looking dependent or old (Lee et al., 2007) (Steele et al., 2009). During the focus group sessions, this was also affirmed by the elderly participants, see insights Chapter 3.2.4.

Culture

Culture is defined as 'The shared patterns of behaviours and interactions, cognitive constructs, and affective understanding that are learned through a process of socialization. These shared patterns identify the members of a culture group while also distinguishing those of another group' (University of Minnesota, 2020). Therefore, culture has a significant effect on people's behaviour, beliefs, and decisions. Thus, it is not surprising that culture influences an individual's acceptance and use of wearable technology.

D - Physical aspects

Wearable technology functions as part of the human body; thus, the physical effect on the wearer will influence the acceptance. Buenaflor and Kim (2013) use three key components to describe how these physical properties affect user adaptation.

1. Physical comfort and safety - the absence of physical burden or disturbance on the wearer. These two essential aspects are determined by the portability and wearability of the device (Rosenthal et al., 2013). Important factors affecting comfort are size, weight and how it affects body movement. Most people prefer a useful and functional portable device that has minimal bulk, weight and movement constraints (Bodine et al, 2003). The other barrier is safety. People might experience fear for the possibility of technical failure and that the device might cause physical harm (Boscart et al., 2008).

2. Aesthetic and appearance - devices must look and feel pleasant as they define a group identity. People identify each other as being part of a certain group, based on looks. A technological wristband might give off 'handicapped', 'sportive' or 'high-tech', depending on aesthetics and context (Dunne, 2010). This emotional impact of wearable devices on the user therefore greatly influences its adoption. Findings from the focus group showed that older people prefer a wearable sensor or panic alarm system that are smaller, less obtrusive and discreet. Additionally, they suggested that the device be disguised into a watch or a ring, as they did not want to be seen wearing a health monitoring device.

3. Mobility - people are naturally mobile and, therefore, for the wearable device to be suitable, the size, weight, placement and attachment to the body must be considered. The advantage of wearables is that they are always with the wearer; therefore usable at any time and place. This is a positive factor in its acceptance. As for this project the device aims to improve the wearer's mobility, it is of the utmost importance that the placement and application does not restrict the user's movements and gait.

E- Demographic characteristics

One other very important aspect of wearable adaptation is the user's demographics. As indicated in Chapter 1.2.3, people experience physical, cognitive, emotional and social changes as they age. This is why in the context of technology, many elderly people find computer systems difficult to understand (Steele et al,. 2009). Age therefore plays a great role in determining whether services of wearable devices are useful to and usable by the wearer.

In addition to age, gender also affects the acceptance of wearable devices. In a study evaluating the acceptance of smart shirts, Schaar and Ziefle (2011) found that males accept technology more than females. A higher proportion of men have a high level of interest in the use of new inventions and technologies (Rudell, 1991). When designing the smart shoe system, these two demographic characteristics affecting user adaptation should be kept in mind, allowing for the product to fit all demographic groups within the target audience.

F - Technical experience

A user's previous exposure to various forms of technological applications has a substantial effect on their acceptance of a wearable device. People with technical experience tend to be more confident and are expected to be more willing to use wearables, as they know technology can benefit them (Kurkovsky et al., 2008). Duval et al., (2010) reported that smart clothes aroused greater interest and were more accepted in Japan than in France. This could be attributed to the greater availability of and familiarity with technology in Japan (Duval et al., 2010). Similarly, but on a much smaller scale, in the Netherlands, the smart shoe system might be more accepted by elderly people living close to or in a big city, as opposed to the elderly living in the more rural towns and villages.

3.5.3 Summary of insights

A

Fundamental need

i) The wearable device should contain one of the two primal elements from Maslow's hierarchical pyramid of needs, and it should express this element to the user (physiological and/or safety)

B

Cognitive attitude

i) There should be more advantages than disadvantages to the wearable device (perceived usefulness).
ii) The user should be confident in using the device (ease of use).
iii) The user should not fear wrong usage of the device(ease of use).

C

Social aspect

i) There should be transparency in which data is being collected (privacy)
ii) The social weight from people close to the user should be at an acceptable level (social influence and culture)

D

Physical aspects

i) The wearable device should not restrict the user in their gait or movement (comfort and mobility)
ii) The product-image should fit with the group identity that the user wants to express with this device (aesthetic and appearance)
iii) The user should not fear the possibility of technical failure or physical harm (safety)

E

Demographic characteristics

i) The benefits of the wearable device should be experienced in a similar fashion by all demographic groups within the target audience (age and gender)

F

Technical experience

i) The wearable device should contain characteristics and traits that are already known to people, such as haptic feedback elements

Next steps

The insights gathered in Chapters 3.4 and 3.5 can be used as a foundation for the list of requirements in the defining solution phase. All the elements for successful user adaptation must be present in the final design to safeguard the motivational aspect in Fogg's model. Namely, the elderly need to be persuaded (and stay persuaded) to change their behaviour.

3.6 Key insights and message

- The system's architecture, presented in Chapter 3.1 will also be able to obtain data on the MTC parameter, as well as all other spatio-temporal gait parameters depicted in Chapter 2.2.1. Therefore, combining the analysis and data of these parameters with the intervention targeting the primary variable of the MTC, fall-risk assessment will be further optimized.
- GaitUp's products best characterize the goal of this project: measuring movement disorders to quantify and detect pathological gait. However, this PhysiLog is aimed at health professionals, and not the elderly user. Removing this 'middleman', the physician or GP, the focus of the product will shift towards the end-user. Certain design-aspects therefore need to change, greatly dependent on the target group's needs and wishes.
- Lately, design thinking has been applying design and technology intervention that can contribute to 'autonomous ageing'. Through a user-centered approach, it can be assured that the products are designed with care, and are made familiar, usable and desirable by the elderly, vital when designing for this topic. Therefore, focus groups were organized, which showed the many views of the target group regarding the topic of mobility, falls and one's independence. The insights derived from the focus group sessions should be translated in distinct user needs.
- Both experts agree that analysing the MTC by a wearable device is very interesting and shows great potential as a falls prevention strategy, as long as it is designed correctly. This means that the intervention or primary signal saying 'Lift your feet' should not scare the elderly, as this could potentially backfire. Additionally, preferably, the analysis of as many elements that matter to falls prevention and mobility issues must be incorporated into the product, as a sole focus and optimization of just one parameter could lead to a false sense of security.
- Fogg's model for persuasive design shows that behaviour is a product of three factors: motivation, ability and a trigger. For the elderly to adopt a more healthy walk, all three factors need to be incorporated and reflected in the final product design. Keeping the elderly motivated can be achieved by using the insights gain on the six factors affecting the acceptance of wearable devices

Phase (c) showcased a broad analysis of the context in which the product will come about. A first exploration into the sensing technology, capable of monitoring the MTC- and other gait variables, showed that the smart system's architecture is presumably small enough to be integrated in an insole.

Through including the target group in the design process, insights were gained on the needs and wants of the elderly. These should be carefully looked after through the course of the project.

Experts indicated that besides avoiding a fals sense of security, through expanding upon the analysis of parameters, it is also crucial for the smart system to intervene in a effectively safe fashion and does not scare the elderly.

Additionally, this phase showed that in order to design such a product for behavioural change, keeping the elderly engaged to using such as wearable device, the product needs to be carefully designed. The behavioural model for persuasive design and the user adaptation framework will be used throughout the design phase to meet these requirements.

chapter 4

Synthesis

This chapter showcases the findings from the background, literature and 'field' research. All of which are funnelling it into manageable information, i.e. with the use of a problem definition, context scenarios and stakeholder needs.

In this chapter:

4.1 Problem definition and scope
4.2 Context scenarios
4.3 User needs
4.4 Personas

4.1 Problem definition and scope

> Elderly people experience muscle and balance deterioration due to ageing. Among other things, this contributes to them lifting their feet less high off the ground during walking, a parameter known as the minimum toe clearance (MTC). This so-called shuffling gait frequently results in a trip and fall. A solution must be found in capturing the moment before a fall, then when the variability in MTC increases to risky proportions. This risk must then be transferred to the user as a warning, so that he or she can respond and correct, and hence, a possible fall can be prevented.

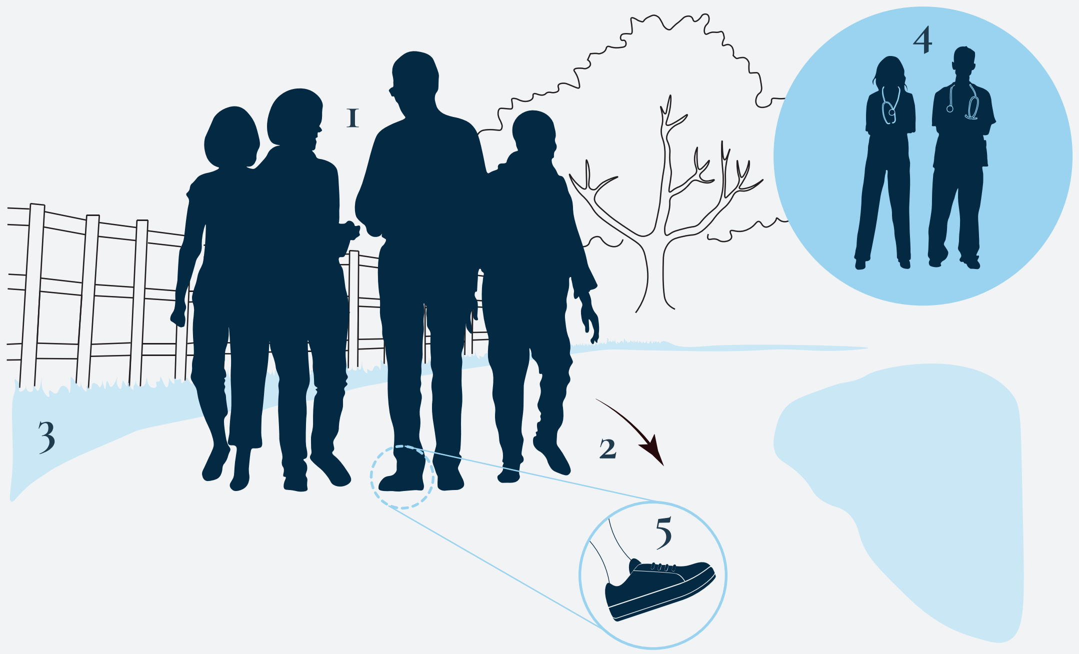


Figure 4.1: Visual depiction of the problem definition and scope.

1 - *The elderly*

The product will target the healthy elderly population of 60 years and older, those who don't experience gait impairments due to (chronic) diseases or illnesses, but do experience a physical decline. They notice their level of mobility is decreasing and are more and more prone to experience a fall. They live independently in their family home or apartment, where their children have moved out, with their partner at the most.

2 - *A learning curve*

As the product will greatly consist of technological components and products like wearable devices are quite new for the older generation, a learning curve is needed and essential in order for the user to operate the product correctly. This could also be concluded through research into wearable devices and insights gained from interviewing care professionals (Chapters 3.2 and 3.4). As there is a certain old age where this learning curve becomes increasingly shallow, the old elderly will be excluded from the target audience. Therefore, the final intended user is the healthy elderly person in the age range of 60-75.

3 - *The environment*

As was characterized by the findings resulting from the focus group depicted in Chapter 3.3, there are distinct differences between the types of users of the eventual product. Some might use the product every day, as the more active elderly often go out for chores and activities, while the 'inactive' elderly might stay at home more. However, all elderly walk/move about and the risk of a trip is lurking everywhere, also when walking on a flat surface in one's home.

Therefore, the intended environment where this product will be used in is not limited to a specific area. The problem takes place in- or outside the home, on even or slightly uneven surfaces. Both indoor and outdoor usage will therefore be stimulated in the design.

4 - *The care professional*

Through research into current solutions to the defined problem and expert interview, it was concluded that the care professional continues to play an important role in aiding or supplying the older generation with wearable devices or biosensors. All falls prevention solutions currently include the feature of alerting the product wearer's physician when a (possible) fall is detected. This stakeholder will also be included in the design of the smart shoe.

5 - *The smart shoe*

A solution to the problem stated lies in capturing the moment before a fall, with the use of technology incorporated in the shoe. Similarly to GaitUp's product PhysiLog (Chapter 3.2), the eventual product will be located around the user's foot. It should be made possible to use the sensing device in different kinds of footwear (derived from focus group-insights), resulting in a detachable 'accessory' type of product.

Solution space

The solution is a detachable product located in or on the shoe which analyses the wearer's gait parameters, with in particular the (variability of the) MTC. The product-solution must offer a real-time, unobtrusive but distinct signal to the user when risk is detected, in order to make it possible for the user to respond, and hence, prevent a possible fall.

Additional concrete information, in the form of exercises and education, must also be provided and incorporated, to improve the user's overall gait and balance.

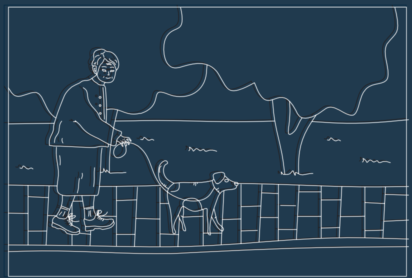
Lastly, the role of the (elderly) care professionals should be considered, as they play a vital and decisive role.

4.2 The current and envisioned context scenario

The previous chapter focused on the problem definition and subsequent project's scope and solution space for this thesis' to be designed product. To clarify and portray this solution space, the product intervention's envisioned impact, the context scenario of the current situation regarding elderly fallers and the envisioned situation are illustrated in this chapter.

The scenario portrayed on the left-hand side, tells the story about the intended users in the current situation, see Figure 4.1. The scenario on the right-hand side tells the story of the envisioned situation, see Figure 4.2.

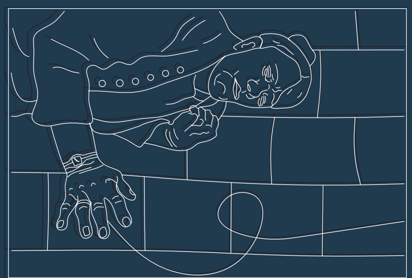
Figure 4.1: The current situation.



Susie is walking her dog Momo in the park near her house.

While walking along the paths, she bumps her toe against uneven pavement.

Due to the unexpected event, she loses her balance and falls.



Before she knows it, Susie is on the ground and a pain shoots down to her right wrist.

After sitting upright, she knows that something is not right

A kind bystander offers his help.

The kind man offers to take her to the nearest general practitioner.

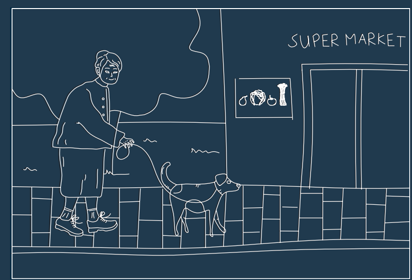
Unfortunately, Susie's wrist is fractured. She will need treatment in the upcoming weeks.

Figure 4.2: The desired situation.

Susie is walking her dog Momo in the park near her house.

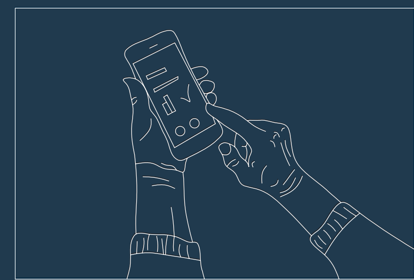
While walking along the paths, her smart insoles detect an increased risk of tripping, due to a low MTC.

The impending danger is signalled to Susie, making her pay more attention to her way of walking.



Through now lifting her feet properly, she arrives at the supermarket safely.

She's glad to be back home, together with her furry friends.



One week later, Susie opens the smart insole-application to witness her progress.

She's been doing well, her gait has improved!

During a standard check-up at the general practitioner's office, Susie shares her progress with her GP.

4.3 User needs

The desired future scenario, presented in the previous chapter, is a rough depiction of how the product will be aiding the elderly population in preventing falls. The elderly's needs and wants, leading to certain product aspects depicted there, need further attention.

As stated before, a human-centered approach to design a concept for the elderly requires designing for their needs and goals. Field research from Chapter 3.2, literature research from Chapter 3.4 and existing solutions presented in Chapter 3.1 show what these overall needs are.

4.3.1 Needs from the elderly

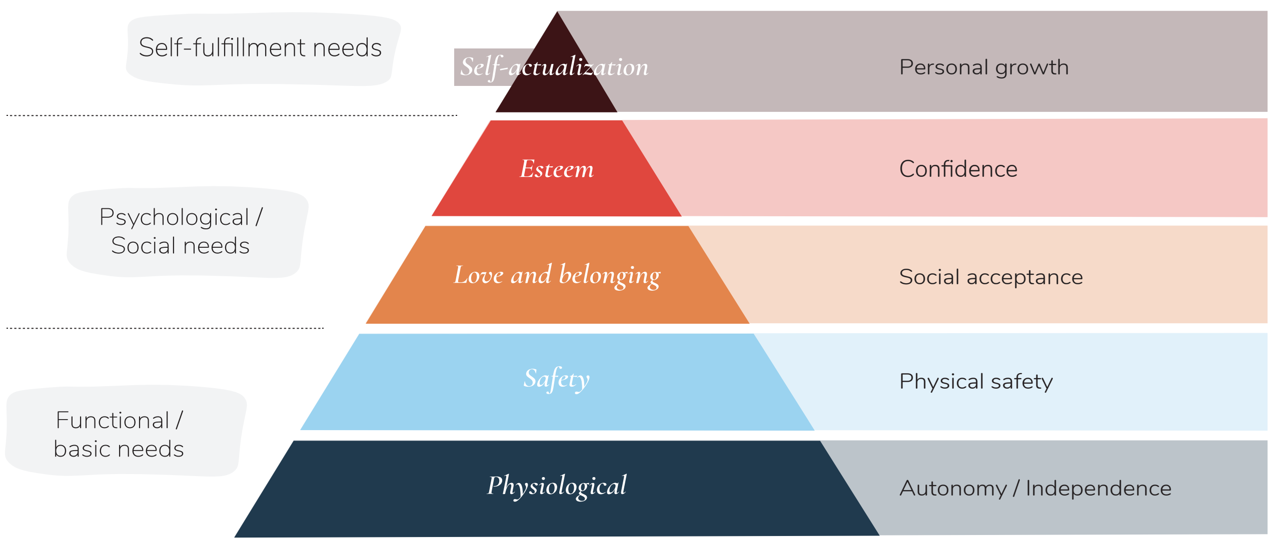
These obtained needs are gathered and categorized into different categories. Maslow's hierarchy of needs-pyramid is used for inspiration, to make sure all levels of human needs (basic, psychological and self-fulfilment) are looked after and the needs of the elderly are taken care of in detail-levels (1958).

Autonomy / Independence
  The need to be autonomously mobile
Physical safety
  The need to be healthy
Social acceptance
  The need to be accepted and fit in with others
Confidence
  The need to feel secure and confident in achieving
Personal growth
  The need for help in achieving personal goals

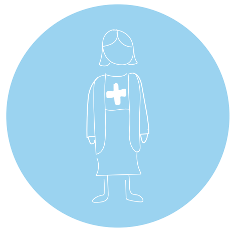
These needs are used throughout the design of the concept. The final concept focuses on needs like stimulating and informing the user in optimizing their gait and remaining active, in a discrete manner. Figure 4.3 shows the categories of needs with examples gathered from user research. These detailed needs do not necessarily belong at the same level in the pyramid, but rather describe the main overarching need.

Subsequently, the needs from this chapter are used in creating personas, see Chapter 4.4. Both the user and project needs were combined and transferred into three lists of requirements, to be used throughout the design of the project's concept. These lists can be found in Chapter 5.3.

Figure 4.3: The main user needs' importance plotted against Maslow's hierarchy of needs (1958).



Autonomy / independence
Being autonomously mobile, the need for ...
- being able to get from point A to point B
- easier mobility
- being able to get out of the house independently
- emotional stability
- to be in control of your quality of life



Physical safety
Being healthy, the need for ...
- effortless walking
- reliable information on a healthy gait
- information on the risks of an unhealthy gait
- education on the consequences of falls
- the truth when something's wrong, no sweet-talking

Social acceptance
Being liked / accepted, the need for ...
- not being stigmatized or classified
- feeling the same as any other, fitting in
- discreet help, when needed, aid that is unnoticeable to others
- not feeling ashamed when wearing the concept-design
- keeping up with the times

Confidence
Bing confident, the need for ...
- clear and reliable information
- convenient stimulation
- being able to witness progress and results
- enjoying physical exercise
- knowing your limits and possibilities

Personal growth
Being stimulated, the need for ...
- being inspired
- tips on how to get even better
- the possibility to grow
- taking matters in your own hands
- finding your balance

4.4 Personas

As a next step the stakeholder needs are visually represented by the creation of personas. These two personas are based off of the conducted literature research and focus groups and interviews with experts.

Being representations of the intended users, personas describe and visualize their behaviour, values and needs (Delft Design Guide (2009). The goal of constructing the personas is to develop a product-concept based on these three characteristics, also, they help in expressing understanding and empathy with the elderly.

Both personas were created based on literature (background) research, insights from expert interviews and, most importantly, colourful insights derived from the focus groups (described in Chapter 3.2.4).

The focus groups showed that the married elderly people rely on their partner when needing help, and therefore wondered who older single people turn to for aid or advice. Sitting down with the elderly also showed that they are still capable of doing much, and if not, they knew how to compromise and still live their life to the fullest. Also, the participants broke the stigma of people thinking that elderly don't know much about the latest advancements in technology, as some made use of fitness trackers and smartwatches and even shared their knowledge of exoskeletons, for example. Technology should subtly empower them and aid them in remaining independent throughout the years. They know about falls, but admitted more education would be welcome.

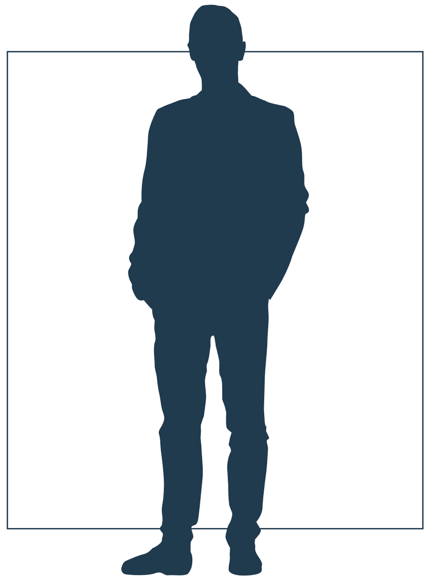
During the latter activity, it became clear that, as for countless other aspects, there are two extremes to every behaviour, value or need; many elderly float somewhere in the middle or lean a bit to one side. For example, energy put in exercising, experience with technology and feelings towards walking as activity. Hence, these differences in characteristics and traits were captured in the personas created, representing the diverse target audience.

Two personas are created: Alexandra and John illustrated in Figures 4.4 and 4.5.

74-year-old Alexandra has been living by herself ever since her late husband passed away three years ago. She lives on the first floor of a small apartment building, and uses the elevator to get up and down.

During the day, she likes to read books on art or paint herself, and during the nights and weekends she goes out to the theatre or play some cards with her long-time friends. Alexandra often does her grocery shopping together with her eldest daughter, who lives just five minutes away.

Two months ago, Alexandra made an unfortunate fall, which resulted in a wrist fracture. Ever since, she has been using her walking aid more to help her get around town.



John is a 63-year-old, who lives in the suburbs of Nijmegen, together with his wife Judy. They own a detached house with a stretched-out garden, where he likes to spend his weekends gardening and doing odd jobs around the house. After a full day of working as a grass and lawn specialist, John usually goes out for a jog, reads a book on his e-reader or enjoys a glass of wine with his wife.

John is a healthy middle-aged man, however, lately he has been having slight knee problems. He visits a physiotherapist every other week, who has almost brought him back to his old self.

He is quite tech-savvy for his age, as he uses an iPad for work and keeps track of his sporting activities with his fitness tracker.

Alexandra, 74

profile

Age
74 years old

Civil status
Widow, 3 children

Housing situation
Alone, in an apartment

Profession
Retired curator

Hobbies
Painting, reading, going to the theatre, evening drinks and games with friends

story

74-year-old Alexandra has been living by herself ever since her late husband passed away three years ago. She lives on the first floor of a small apartment building, and uses the elevator to get up and down.

During the day, she likes to read books on art or paint herself, and during the nights and weekends she goes out to the theatre or play some cards with her long-time friends. Alexandra often does her grocery shopping together with her eldest daughter, who lives just five minutes away.

Two months ago, Alexandra made an unfortunate fall, which resulted in a wrist fracture. Ever since, she has been using her walking aid more to help her get around town.

frequently uses

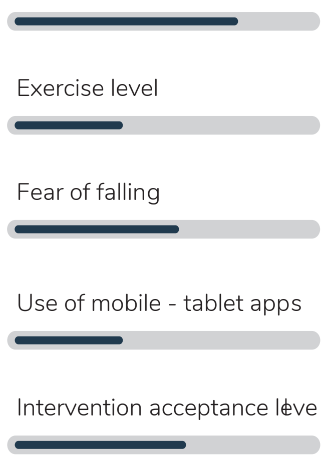

walking aid


simple smartphone


books


paint brushes

characteristics



needs

- A device that alerts her daughter when she makes another fall
- An aid that will improve her overall gait, endorsed by her doctor
- A device that can be worn in various pairs of shoes

wants

- Tips on easy-to-perform exercises to restore her balance
- An aid that is hidden away/ integrated and does not bother her too much
- Reminders to do her exercises

> *" I want an attractive and stylish aid. Because, when you wear yet another wristband of some sort, others will ask: 'Gosh, what do you have there.' "*

Figure 4.4: Persona Alexandra.

John, 63

profile

Age
63 years old

Civil status
Married, has two children

Housing situation
In a single family home with his wife

Profession
Grass and lawn specialist

Hobbies
Biking, reading, jogging, doing odd jobs around the house, cooking.

story

John is a 63-year-old, who lives in the suburbs of Nijmegen, together with his wife Judy. They own a detached house with a stretched-out garden, where he likes to spend his weekends gardening and doing odd jobs around the house. After a full day of working as a grass and lawn specialist, John usually goes out for a jog, reads a book on his e-reader or enjoys a glass of wine with his wife.

John is a healthy middle-aged man, however, lately he has been having slight knee problems. He visits a physiotherapist every other week, who has almost brought him back to his old self.

He is quite tech-savvy for his age, as he uses an iPad for work and keeps track of his sporting activities with his fitness tracker.

frequently uses

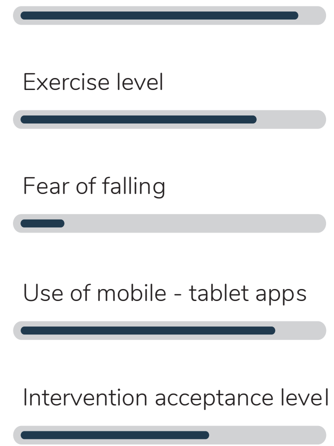

e-reader


sneakers


iPad


bike

characteristics



needs

- Customizability of the displayed information
- Being able to track his progress daily
- Not being stigmatized or classified as 'that elderly guy'

wants

- Tailored feedback on his sporting activities
- The possibility to deliberately take a stroll/ shufße along the boulevard when he wants to
- Supportive insoles

> *" I sometimes see those glasses that have technology implemented in the temples, allowing you to give commands with your voice; I love that you can do things like that with technology nowadays.' "*

Figure 4.5: Persona John.

chapter 5

Design Direction

As an answer to the problem definition, a design goal with accessory interaction visions are drafted. Similarly as to how the design goal has been split up into three different segments, three separate lists of requirements are drafted.

In this chapter:

5.1 Design goal
5.2 Interaction visions
5.3 Lists of requirements

5.1 Design goal

As an answer to the problem definition in Chapter 4.1, a design goal is drafted. As this is a Design for Interaction Master project, the overall aim is to create a result that enables the user to achieve their objective(s) in the best way possible, adding a benefit for the context of use.

Design of a concept that prevents falls among elderly (60-75), by real-time monitoring of the user's MTC variable and instant signalling of apparent risk therein, in addition, clarifying this through supportive information and (balance) exercises on a separate UI.

The concept being developed is evaluated according to this benefit. Simply said, it translates into

'Designing something that has a specific effect on someone in a certain way'.

That something is a shoe equipped with a smart system, which analyses the user's gait pattern, specifically the MTC parameters. If the user is at risk of a fall, a signal will be sent out to the user. A user interface (an App) will inform and educate the user on how to optimize their gait.

The effect is the design goal, which is to prevent falls.

Someone is the elderly population, and in particular, the elderly population that experiences declines and has the intent to remain autonomously mobile for as long as possible. The targeted age group is 60 - 75, due to the technological theshold.

In a certain way is translated into an 'interaction vision', which is showcased in the next chapter.

The goal is to use a combination of at least two separate products, a smart system in the shoe, a signalling device and an App, which work together to warn and inform the user about the quality of their MTC- and other gait parameters.

real-time monitoring → 1. Detect

The smart system integrated in the shoe analysing the user's gait, in particularly the MTC. The smart system's requirements will be included in the List of Requirements in Chapter 5.3 and the most important design elements will be discussed in Chapter 6.1.

instant signalling → 2. Warn

A wearable device that gives off a warning signal at times when the smart system notices that the user is at risk of a fall. The method of feedback and the location of this wearable device will be determined later on through (experimental) research, see Chapters 6.2 and 6.3..

supportive information → 3. Inform

An accessory user interface supports the warning signal with information on the user's gait pattern, in particular the MTC parameter, and on additional education surrounding the topic of mobility and falls in elderly people. The design of the mobile application's UI will be explored in Chapter 6.4.

5.2 Interaction visions

An interaction vision is a creative design technique to address the intended character of the interactions with a future design concept. When developing an interaction vision, one thinks about how the interacting with the concept should be experienced by its user(s). What sort of emotions should they feel when using it? Subsequently, what means could designer apply to evoke or support this particular feeling or experience?

The interactions visions were developed after gaining rich insights through the organization of the focus groups. In the same way as the preceding chapter, the signalling-concept (the part of the product with which the user can interact with / or experience things with) is split up into two parts, as they portray different user experiences. Hence, two different interaction visions are constructed: one for the 'primary signal' (warning signal) and the 'secondary signal' (the informational mobile application).

5.2.1 Primary signal - Warn

The interaction with the haptic feedback should be attentive, safe, direct, discrete and reliable. It should have the same feeling as when you are driving on the highway and drifting your car off the lane a little, hitting a rumble strip that alerts you of the potential danger of driving off the road. The interaction vision shows that the primary signal's main function is to alert the user in being attentive, in a safe manner. Subsequently, it is direct and reliable, as it is proven to work in alerting the user and there's only one way to interpret this warning. Additionally, as you (or the people with you in the car) are the only one receiving the warning, the alert is discrete.

instant signalling

The interaction with the primary signal should be like driving over a rumble strip which alerts you of possible upcoming danger.

Figure 5.1: A truck driving next to a rumble strip.

Attentive - The main feeling the product should invoke is attentiveness. With the alert, the user should be made aware of the potential unsafe situation.

Safe - The vibration administered should not scare or unbalance the user.

Direct - The device should alert in a direct manner, meaning, there should only be one way to interpret the signal. It should feel easy to understand, without difficulty or ambiguity.

Discrete - When being alerted, the signal should only be noticeable by you and not to you people surrounding you.

Reliable - Reliable in a way that the user is able to trust the device and can depend on it.

5.2.2 Secondary signal - Inform

The interaction with the mobile application should be motivational, realistic, focused constructive and empowering. It should have the same feeling as when you are visiting the gym for a work-out session with your personal trainer. Your trainer guiding you and keeping you motivated for change. This is done in a realistic and straightforward matter, giving advice only at times when necessary; maintaining the focus. Small and realistic steps lead to the best results, since you're less likely to give up (Fogg, 2009). Failing heavy exercises results in demotivation. The personal trainer is there to help in reaching the goal through constructive and empowering feedback.

supportive information

The interaction with the secondary signal should be like the relation between someone and his personal trainer at the gym.

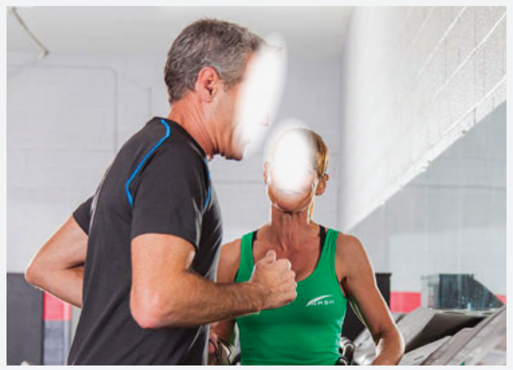


Figure 5.2: An athlete and his personal trainer.

Motivational - The main feeling the signal should invoke is to give the user purpose and help to prevent giving up; to achieve behavioural change.

Realistic - The information and education provided on exercises should be realistic and easy to achieve, both in its goal as in its way of reaching that goal.

Straightforward - The advice given should be honest and direct, and not signal more than necessary. It should be obtrusive but give clear directions when necessary.

Constructive - The secondary signalling should be constructive and positive, to make the change towards the new desired behaviour experienced as a pleasant one.

Empowering - The device should enable the user to feel proud of his or her efforts and aid the user in achieving their goals.

5.3 List of requirements

A list of requirements is drafted through conducting an analysis of all information gathered on the design problem. The eventual product-design should comply with these requirements, as it states the important characteristics that a design must meet in order to be successful.

Similarly as to how the design goal has been split up into three different segments, three separate lists of requirements are drafted.

real-time monitoring

01

The design should real-time analyse and monitor the user's gait through a smart system integrated in the shoe.

	Requirements // 'Detect'	*Reference*
General	1.1 The product should aid falls prevention • 1.1.1 The product should analyse the motion of both feet 1.2 The product should not restrict the user in their gait or movement 1.3 The smart system should be able to analyse and monitor all spatio-temporal gait parameters of the wearer, with a focus on the minimal toe clearance parameters • 1.3.1 As many elements to falls prevention and mobility issues must be incorporated in the product 1.4 The product should be able to detect a fall • 1.4.1 The product should be able to warn a family member of healthcare professional at the event of a fall 1.5 The product should turn on/generate data automatically when the footwear is being worn - when the weight of the user is detected • 1.5.1 The product should turn/generate data on when movement is detected • 1.5.2 The product should not turn on/ generate data when the footwear which hold the smart system is being picked up by hand and positioned elsewhere 1.6 The product should turn off automatically, after 1 minute of not detecting movement 1.7 The product should be low maintenance • 1.7.1 The product should be kept clean easily 1.8 Using the device should be made as smooth as possible • 1.8.1 The batteries within the smart system should be rechargeable, without the need to remove/detach the product from the footwear • The product should include a wireless charging station 1.9 The product should not evokefear of possible technical failure or physical harm • 1.9.1 The product should not include a user interface • The product package should include a detailed description of the product's functions and characteristics 1.10 There should be transparency in which data is being collected	Chapter 2.3.2 Chapter 3.5.3 Chapter 2.3.1 Chapter 3.3.1 Chapter 3.1.4 - - Chapter 3.4.3 Chapter 3.5.3 Chapter 3.5.3 Chapter 3.5.3
Appearance	1.11 The product should prevent stigma and discrimination of the elderly • 1.11.1 The product should be positioned unobtrusively in or around the shoe 1.12 The product should be made water-proof	Chapter 3.2.3 -
Size	1.13 The product should be small enought to be embedded in the insole • 1.13.1 The product should be interchangeable between types of footwear • 1.13.2 The product should be designed for the more sturdy types of footwear (no slippers e.g) • 1.13.3 The product should be made as compact as possible	Chapter 3.1.1 Chapter 2.4
Weight	1.14 The product should be light-weight (presumably, no more than 100 gram) to increase ease of use	Chapter 3.5.3

instant signalling

02

The design should real-time warn the product's wearer when apparant risk is present, through a technological intervention.

	Requirements // 'Warn'	*Reference*
General	2.1 The product should improve the wearer's gait through instant signalling the user when apparent falls risk is present, based on an analysis of MTC parameter 2.2 The product should not restrict the user in their gait or other types of movement 2.3 The signal should target one of the five human senses	Chapter 2.3.2 Chapter 3.5.3 Chapter 6.2.1
Safety	2.4 The signal should not provoke shock when warning the user • 2.4.1 The signal of the product should be clearly felt, though, not too intrusive or vehement • 2.4.2 The signal should transfer the information most effectively and correctly 2.5 The product's feedback should be easy to interpret • 2.5.1 The product should not have a second function, to avoid confusion • 2.5.2 The instant feedback should only include one type of feedback, with one meaning 2.6 The product should not be easy to misuse • 2.6.1 The product should not include a user interface • 2.6.2 The product should look like any other accessory 2.7 The effect from the products' intervention should persist as long as possible • 2.7.1 The product's feedback stimulus should be positioned so that the risk is clearly addressed for the longest period of time; adjust the gait for as long as they can recall	Chapter 3.3.1 Chapter 3.5.3 Chapter 3.5.3 Chapter 2.3.2
Placement	2.8 The product should be easy to wear • 2.8.1 In the morning, the user should need no extra steps to get ready for the day 2.9 The product should not cause discomfort over time • 2.9.1 The product should be strategically placed to evade any type of restriction 2.9 The product must be in close contact with the skin or should be observable at all time • 2.9.1 The product must be placed on a sensitive area / skin site; there where the skin is thin and new to the touch but not too sensitive	Chapter 3.5.3 Chapter 3.5.3 Chapter 3.2.3
Appearance	2.10 The product should be unobtrusive • 2.10.1 The signal of the product should be distinct and clear, but not obtrusive • 2.10.2 The signal should only be perceptible to the user 2.11 The product should not look like an aid • 2.11.1 Preferably, the produt should not be noticeable/ perceptible • 2.11.2 The product should have the appearance of an accessory	Chapter 3.2.3 Chapter 3.2.3
Size	2.12 The product should be made as compact as possible	Chapter 3.5.3
Weight	2.13 The product should be light-weight, (presumably, no more than 50 gram)	Chapter 3.5.3

supportive information

03

An accessory user interface supporting the warning signal with concrete information and advice on sufficient and safe exercise to improve the MTC.

	Requirements // 'Inform'	*Reference*
System	3.1 The app should evoke motivation in the user to optimize their gait 3.2 The app should be installable on any mobile device 3.3 It should be easy and non-obtrusive to register as a new user • 3.3.1 The register process only needs to incorporate the necessary steps for personalized use • 3.3.2 It should not be made possible to make use of the device without registering with the necessary information 3.4 The app should be installable based on the characteristics of the user 3.5 The product's interface should have a 'hidden' off-button. This switches off the smart system at moments or in a context when the user willingly decides to. • 3.5.1 The off-button needs a two-step confirmation 3.6 There should be transparency in which data is being collected	Chapter 3.4.3 Chapter 3.2.3 Chapter 3.4.3 Chapter 3.2.3 Chapter 3.5.3
User Interface	3.7 The app should be easy to use and made understandable to elderly of 60-75 years old • 3.7.1 The app should have a satisfying and accessible User Experience • 3.7.2 The UI should contain characteristiccs and traits that are already known to people • 3.7.3 The interface should contain one primary colour / Font style and size should be adapted to the target audience / The app should be informative while being structured, clear and adaptable to the user's preference / Interactive elements should be enhanced and made big / Language should be easy to understand, use of icons / Only the necessary amount of information 3.8 The UI of the product should look similar to the mobile applications that the target audience is already using, for example WhatsApp or news-apps 3.9 The user should not fear the possibility of technical failure	Chapter 6.4 (Google, 2020) Chapter 3.5.3 Chapter 3.5.3
Content	3.10 The product should contain the possibility for pairing with the smart system and primary signalling 3.11 The content should fit all demographic groups • 3.11.1 The benefits of the smart insoles, portrayed in the app, should be experienced in a similar fashion by all demographic groups within the target audience 3.12 The product should stimulate the user to participate in physical exercise • 3.12.1 Tai Chi lessons and balane exercises need to be incorporated in the design • 3.12.2 The product should convey notifications to perform physical exercise 3.13 The user should receive feedback on every gait parameter, displayed visually 3.14 Notifications on all additional content, excluding the focus on the status of the gait parameter aiding the intervention, should be made possible to turn off manually	Chapter 2.3.2 Chapter 3.2.3 Chapter 3.2, 3.3 Chapter 3.3.1 Chapter 3.5.3

chapter

6

Conceptualization

In this chapter the complete concept idea is presented: the insoles with smart system, the integrated feedback system and additional UI design (app).

In this chapter:

6.1 The smart insole
6.2 Signalling pt. 1 - Warn
6.3 The effect of the intervention
6.4 Signalling pt. 2 - Inform

6.1 The smart insole

By analysing all information gathered on the design problem, three lists of requirements were constructed accessory to the three segments of the concept idea, as presented in Chapter 5.3. The lists of requirements concretely describe the design objectives, together forming the base of the ideation phase. Through ideating, designing and iterating, the concept design takes shape.

1. Detect

In the coming chapters, the concept ideas will be constructed based on the design objectives. As of now, the smart system integrated in the insoles analyses the gait of the user and, hence, it is an input device that provides data. Principally, the sensing technology analyses the MTC parameters and can detect when an alarming situation occurs. The focus now is to ideate on the optimal design of this smart shoe, whether it is feasible to integrate the smart system into the insole and how the user's interaction with the product should look like. Ideation and iterations will present the concept of the first product segment: detect, as presented in Chapter 6.1.1.

2. Warn

Subsequently, the second issue will be addressed: how will the data of impending danger be transferred to the user through a wearable device? At moments when the smart system detects an increased risk of tripping, this information must be provided to the user instantly, thereby alerting the user of gait shortcomings in order to prevent a possible fall. Here, the focus is in what way the wearable can transfer this information most effectively and correctly, while still being as non-intrusive as possible. In order to further develop the second segment of the concept, explorations on these issues, as well as additional matters, supplementary focused research is conducted on how to warn the elderly user, presented in Chapter 6.2 and 6.3.

3. Inform

Lastly, an accessory user interface, in the form of a mobile application, will substantiate the warning signal with information on the status of the MTC- and other gait parameters. Namely, through background research and expert interviews it was concluded that an intervention targeting the MTC is not enough. This focus should be supported with concrete advice on sufficient and safe exercise, aiding the user in the improvement of their gait with the right knowledge. Here, the focus will be on translating the design objectives derived from the list of requirements to detailed UI components, further detailed in Chapter 6.4. To correctly inform the elderly user, information should be presented at the moment of intervention, but also afterwards, as a way for the elderly to gain knowledge on how to limit the occurrence of the first signal.

6.1.1 The smart system

For effective gait analysis, the combined functional requirements of the smart system, see Chapter 5.3 List of Requirements, that will be discussed in this subchapter are as follows:

1) Must be an untethered, stand-alone (wearable) device
2) Must characterize the motion of both feet
3) Must not affect the normal locomotion of the user
4) Must enable long time monitoring

For affiliation with and adaptation by the target group, the aesthetic requirement of the smart system is as follows (see Chapter 5.3 List of Requirements):

5) Must not look like an aid in order to prevent stigma and discrimination of the elderly

6.1.2 Functional requirements

In Chapter 3.1.1 a rough depiction of the technical components and subsequent architecture necessary for the obtaining and analysis of the gait parameters was presented. This smart system should be integrated in or attached to the shoe of the user.

Individual brainstorming and -writing activities were organized, followed by an online creative session, to ideate on the possibilities of integrating the system in or on the shoe, and other matters. Four peer students were invited to ideate on this matter (Van Boeijen et al., 2014). How-tos were formulated within this group, and ideas were generated on how this system could be embedded into the shoe, see Figure 6.1. Detailed visual representations can be found in Appendix A10.

Figure 6.1: Online creative session in the online collaborative whiteboard platform Miro.

The how-tos or problem statements in the top row, each with accessory solution-ideas (same colour) can be seen here.

Smart insoles

The idea that got most traction was to integrate the smart system into the insole. This was also the preferred placement option that was discussed with the supervisory team from the start of the project. In this way, the product turns into a stand-alone, untethered device which is interchangeable between different types of footwear.

As IMUs can be as small as a human fingernail, see Chapter 3.1, it is possible to integrate this sensor in the insole. However, the exact measurements of the supplementary components within the smart system are unknown. The ESP32 Microcontroller symbolizes the heart of the system, therefore, its size shapes the guiding principle when wanting to integrate the product. Research shows that one ESP32, the ESP32-WROOM-32U, measures 19.2 x 18 x 3.2 mm (ESP32.net, 2020). Regular insoles' heel thicknesses reach up to 25 mm in thickness and the support arch height of orthotic insoles' can reach up to 33 mm (Su et al., 2017). Therefore, for now, it is assumed that when arranged in a strategic way, the whole smart system is small enough to be embedded in the insole, whether it be in the heel or the arch section.

As the second functional requirement for effective gait analysis of the MTC parameter, and especially of other parameters such as step length and time, is characterization of and capturing the motion of both feet. This means that both the wearer's shoes should include smart insoles.

Physical aspects

An important functional requirement is that the insole does not affect the normal locomotion of the user. Additionally, comfort of wearable sensing devices is highly important in fall prediction systems since it entails long-term continuous use (Rajagopalan, 2107). Hence, the smart system should be fully integrated into the insole, made of a supportive and pleasant material. The four most common materials from which insoles are made are foam, gel, cork and leather. As the latter two options are discarded due to the limitations of production techniques, the insoles should be made out of foam or gel. In general, foam works best for cushioning, support, and pressure relief and gel works well for shock absorption (The Insole Store, 2017). To meet the requirements of the insoles being no more than 100 gram, the insoles' material which houses the smart system should be carefully chosen. The requirements regarding the built-in smart system and accessory safety issues, presented in Chapter 6.1.2, will provide further argumentation on this matter.

Charging station

To enable an ongoing analysis of the gait parameters, the smart system is equipped with a power supply, consisting of a rechargeable battery. To improve or maintain one's overall health, it is recommended to walk at least 30 minutes every day (Harvard Health Publishing, 2019). By adding the small steps in or around the house and including a safety factor, it is assumed that the smart system should be able to generate data for a minimum of 2.5 hours per day. Given the requirement that the smart system will automatically turn off after 1 minute of not detecting movement. The battery embedded in the smart insole should therefore have a (daily) battery life of a minimum of 2.5 hours.

As the batteries should be rechargeable without the need to remove the insoles from the housing footwear, as described in the List of Requirements, Chapter 5.3, this should be achieved wirelessly. Therefore, a charging station is designed. When the user takes off his/her shoes at night, he or she can position them on a charging mat. Similar to Nike's Adapt shoes, self-lacing and wireless charging sneakers, the mat holds LED lights to provide visual feedback of the insoles' battery status (Nike, 2020). Similar to these sneakers, lithium-ion batteries will be enclosed in the smart system.

6.1.3 Requirements regarding aesthetics

As described in Chapter 3.5.2, in order for the elderly users to use the product and engage in the behavioural change of optimizing their gait, the product should be noninvasive to the user. The elderly user is more likely to adopt the smart insole if it's unobtrusive and discreet. As the smart system is embedded in an insole, fully subsided in a shoe, the product is invisible to others. The elderly's wish to not wanting to be seen wearing a health monitoring device is therefore fulfilled, at least, with regard to this first product segment.

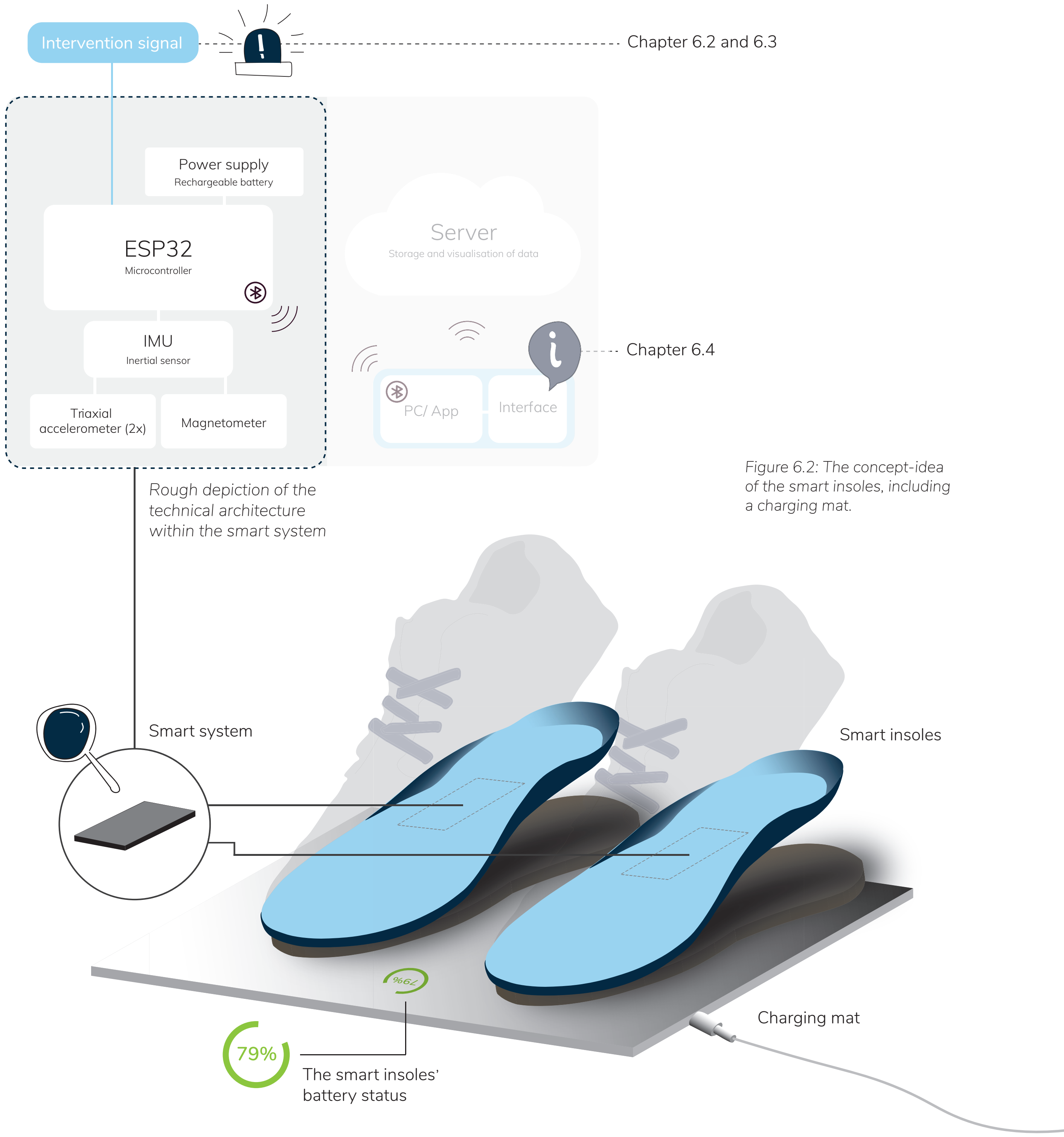


Figure 6.2: The concept-idea of the smart insoles, including a charging mat.

6.1.4 Summary of design decisions

Through weighing all functional and aesthetic requirements, the conclusion is to integrate the smart system in an insole. The thickness of current regular- and orthotic insoles on the market presents the possibility of integrating the smart system herein.

As insoles are fully subsided in the user's shoe, the product will be invisible to others. Thereby, the wearable device is as unobtrusive as it could be.

One of the requirements for effective gait analysis means characterization of the motion of both feet, meaning, the user needs two smart insoles. The rechargeable batteries in the product will need charging after a day of motion sensing, therefore a wireless charging mat is added to the 'product-package'. Other than plugging the charger in the mat, there is are no further user interactions with the product, see Figure6.2.

6.2 Signalling pt. 1 - Warn

It has been established that the product segment enabling gait analysis will consist of two insoles, both with integrated smart systems. However, the question of how the generated data of impending danger should be transferred to the user still needs to be addressed. In this chapter, this second product segment will take shape through focused research and design explorations.

The product's signalling is split into two moments of impact, warn and inform, each with their own aim. The primary signal is the one acting upon the detection of risk, instantly. Whenever the analysed MTC's variability is too high, or the average MTC height is too low, a risky situation could occur. At this moment, the user has to be warned of the impending danger, warning him or her immediately. It does this by outputting an intervention signal; passing along information about this risk by playing in to the senses of the user, see Figure 6.3.

6.2.1 The five senses

The wearable should transfer this information most effectively and correctly, while still being as non-intrusive as possible. As a signal targets one of the five human senses, research was conducted regarding this.

There are five ways in how the human body receives sensory information, these include: sight, hearing, smell, taste and touch, see Figure 6.4.

Looking into which of these would be deployable as the primary signal (warn), the following criteria were acknowledged:

- For the product to give an unobtrusive warning/intervention signal to the user, the alert should not be perceptible by other people, other than the user him/herself. Also, the product/wearable signalling the user should not be visible to others.
- The product should not interfere with the user's every day life or distract too much.
- The alert should be sensible by a larger part of the elderly population, especially by elderly people aged 60-75.

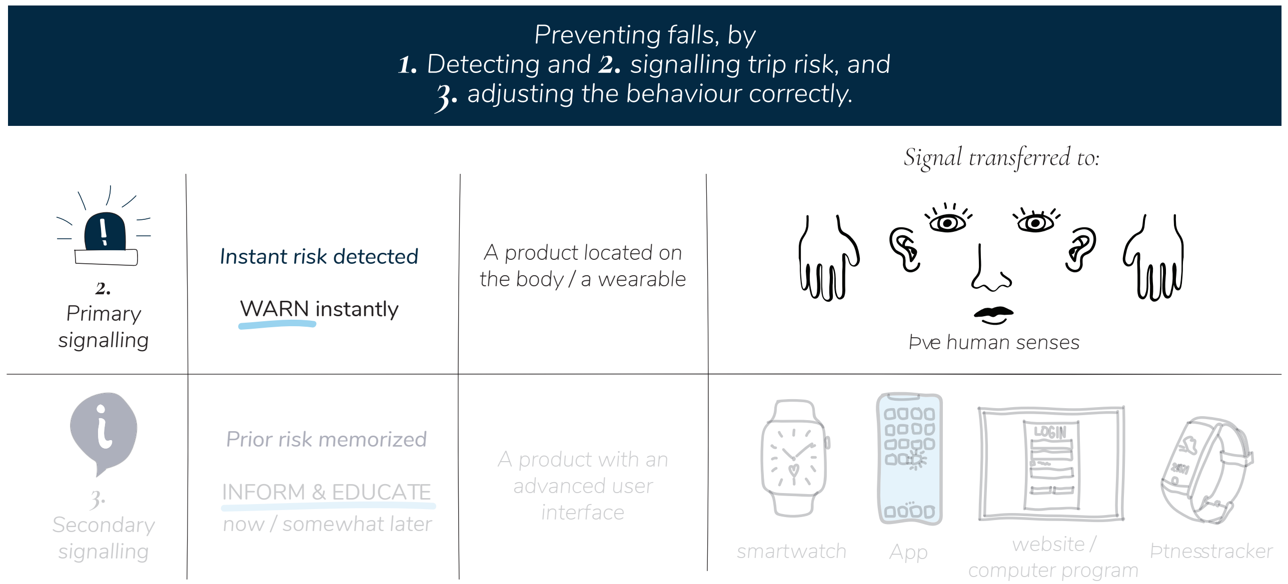


Figure 6.3: The product's two 'stages' of signalling. In this chapter, the primary signalling will be further explored.

Three of the five ways of how humans receive sensory information, sight, hearing and smell, are also largely perceptible by others, unless it is transmitted through wearables at tucked away places (vision) or ear plugs (hearing), for example. Additionally, it is not appropriate to use taste or smell as a warning signal in this context.

The activity of walking mainly relies on one's visual perception, however, secondary duties demand this sense to also focus on the environment, for example. Therefore, considering other sensory channels would reduce this visual load.

Although there is great variability from person to person, four of the five senses significantly diminish with age (Harvard Health Publishing, 2014). The most common changes in sensory functions are: sharpness of focus tends to get worse, hearing loss in both ears and taste and smell become less sharp with ageing. Therefore, all sensory functions decline, apart from the touch.

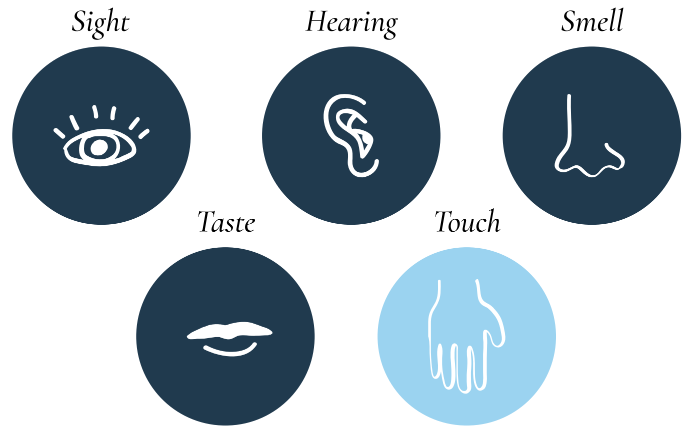


Figure 6.4: The five ways of how humans receive sensory information.

6.2.2 Vibrations

When weighing the criteria, it is self-evident that the product's warning signal should appeal to the touch. Namely, it is most preferred by the user (discreet) and it is the most reliable type of feedback to use for this intricate product. Tactile, or touch feedback is the term applied to sensations felt by the skin. Therefore, the alerting signal will be administered through vibrations on the skin.

Administering pulses or vibrations to the user as a type of feedback is not a new concept in research into fall prevention. For example, vibrotactile feedback placed on the torso has been used to improve rehabilitation in individuals with imbalance and noise-based devices, such as randomly vibrating insoles, could ameliorate age-related impairments in balance control (Wall III, 2010) (Priplata et al., 2003). Additionally, vibration motors, necessary to convey the signal, are inexpensive and small enough to be integrated in a small wearable product (Precision Microdrives, 2017).

6.2.3 Placement of the intervention signal

Now that it has been established that the product's alert will be administered through a vibration, the subsequent focus is the placement of the technology on the user's body. For effective and unobtrusive alerting, the combined functional requirements of the signal are as follows (see Chapter 5.3 List of Requirements):

1) Must not destabilize the user or provoke shock when warning the user
2) Must be in close contact with the skin
3) Must remain fixed on the skin, with minimal moving around
4) Must be placed on a part of the human body sensitive to the touch
5) Must be comfortable when being worn, easy to wear/put on
6) Must not obstruct or hinder the person in everyday activities or movements

For affiliation with and adaptation by the target group, the aesthetic requirements of the vibrating wearable are as follows (see Chapter 5.3 List of Requirements):

7) Must not look like an aid in order to prevent stigma and discrimination of the elderly
8) Can be switched off when desirable

Based on these requirements, research and ideation activities regarding the feedback's placement were conducted and led to the following three locations and accessory product ideas:

- *The bottom of the foot, embedded in the insole*
- *The wrist, embedded in a fixed/semi-tight bracelet*
- *The back of the upper arm, as an adhesive patch*

Additional to the research regarding these three placement options, this product aspect was also discussed within the focus group, as described in chapter 3.3. As the elderly indicated that the product should be out of sight, or discreetly integrated into an already existing accessory or piece of jewellery, the following locations were put forward:

- *The wrist, as an aesthetic wristband or watch*
- *The finger, as an aesthetic ring*
- *The bottom of the foot, embedded in the insole*

Conclusion

As people use their hands a lot, and more specifically their fingers, the vibration would not be distinct enough at all times if the signal would be embedded here. Additionally, the adhesive patch product idea counteracts the aesthetic requirement (7), as a patch on the arm would still look too much like an aid. Therefore, these two options are excluded. As a conclusion, it is decided to focus on a final two options: administering the feedback to either the wrist or the sole of the foot, see Figure 6.5.

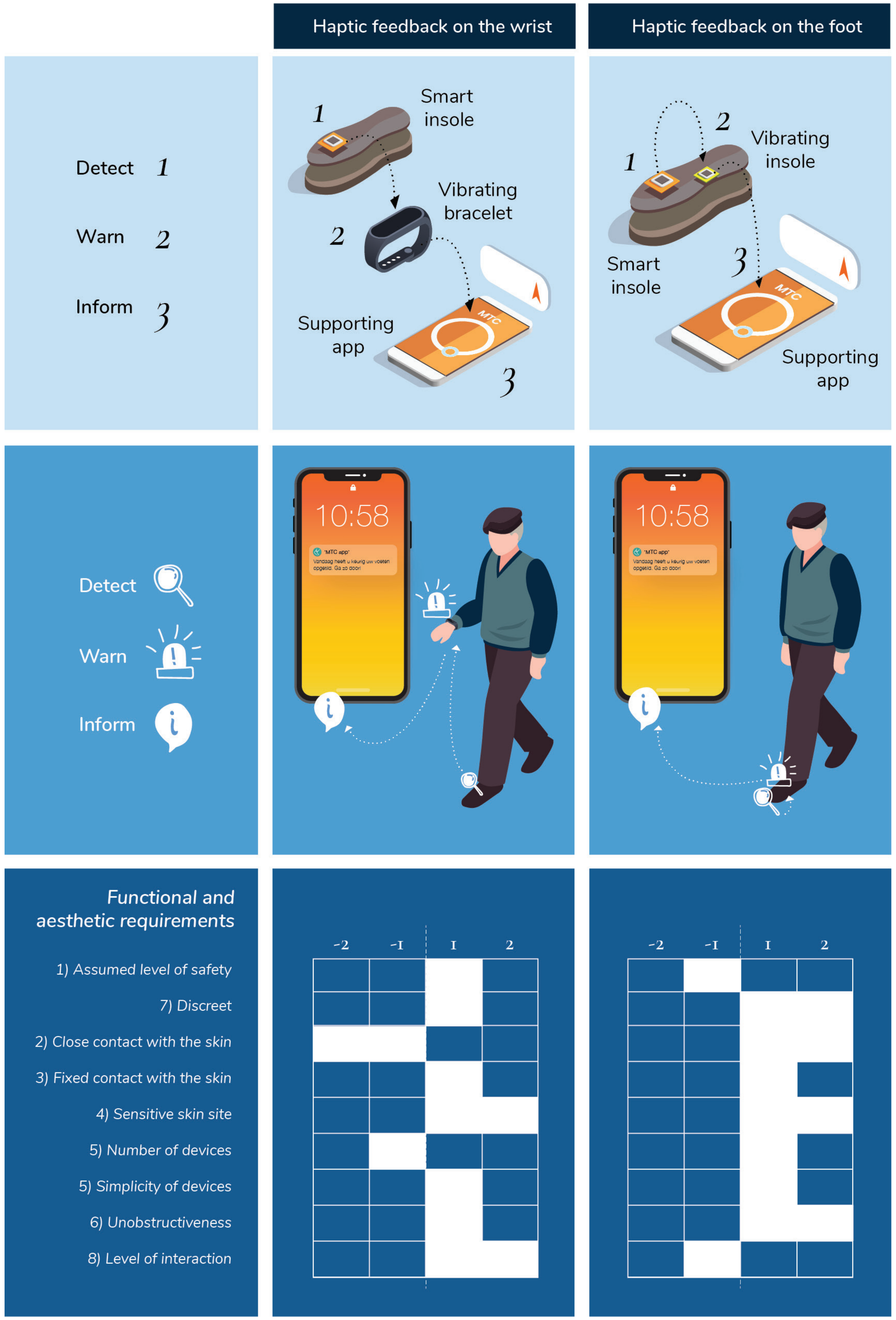


Figure 6.5: The two remaining locations of feedback-placement and accessory visual explanations of how the three segments of the product would operate together.

The two are evaluated against earlier set up functional and aesthetic requirments using a Harris profile (Van Boeijen, 2014).

6.2.3 Shock-effect

Both placement options were evaluated against earlier set up user needs and product requirements, see Harris profile in Figure 6.5. Here, the requirements were ranked according to their improtance for the design project. This resulted in the foot-placement having the best overall score. However, the requirement regarding the safety of the elderly user (must not destabilize the user or provoke shock when warning the user) weighs heavily.

Through discussion with the supervisory team, it is assumed that placing the warning signal on the foot of the elderly user might lead to sudden movements due to a startle response. More so than when placing it on the wrist. In the worst case this could lead to a fall.

To test whether this assumption holds true, and whether the intervention signal has any/sufficient effect on the MTC parameter, it is decided to test this through the use of a prototype. Therefore, with this experimental research, an attempt will be made at testing the viability and the feasibility of the main idea of the smart insole. The aim of the experiment is to study the effect of the intervention when positioned on either location.

6.2.4 Exact placement

Research shows that one of the areas of the foot-sole most sensitive to the touch is the arch medial, the side of the foot arch (P2), see Figure 6.6 (Henning et al., 2009). This was confirmed by Strzalkowski et al. (2015), as their research findings showed that the thresholds of skin sensitivity are partially influenced by mechanical properties of the skin on the foot sole, such as hardness, thickness and stiffness. Hence, the prototype administering the feedback to the foot will be placed on this exact skin site, as it allows for accessible application of a prototype. When placed on the wrist, the signal is administered to the same skin location as that of the wearable devices depicted in Chapter 3.1.3.

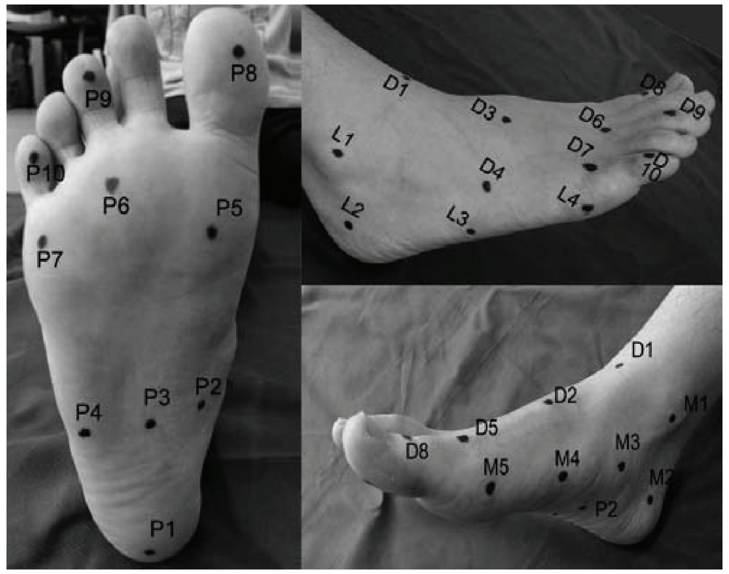


Figure 6.6: Measuring sites for touch and vibration sensory theshold detection. The arch medial of the foot (P2), as well as P8, P9 and P10, show the best sensitivities for touch (Henning et al., 2009).

6.2.5 Summary of design decisions

The most appropriate, unobtrusive and effective type of sensory feedback to deploy as the warning signal, is through the use of haptic feedback, better known as vibrations. The subsequent focus of the placement of this technology, solicited for additional explorations. Through gaining insights on this matter from the target group and conducting research on the thresholds of skin sensitivity at various sites on the body, two remaining options were left: the sole of the foot and the wrist. By evaluating both options against product requirements, resulted in in the foot-placement having the best overall score. However, assumptions regarding the compromised safety of this placement lead to the need for experimental testing, to ascertain the final location of the warning signal.

6.3 The effect of the intervention

As of now, it has been concluded that the product concept will roughly consist of detect-, warn- and inform- functions. The detecting (analysis of the gait) will be done by a smart insole, the informing (Signalling pt. 2, see chapter 6.4) will be achieved by an accessory smartphone app. To ascertain whether the warning signal, the intervention, should be placed on the wrist or on the sole of the foot, an experimental research study is conducted.

As concluded in Chapter 6.2.5, two possible placement options for the intervention signal remain: the wrist and the arch medial of the foot. Testing both options for their compliance to the previously identified user needs and project requirements resulted in the foot placement obtaining the best overall score. However, there are concerns regarding the wearer's safety for this placement on the body. Namely, that in the case of an intervention, the warning signal might lead to sudden movements or an impaired balance due to a startle response. In the worst case this could perhaps lead to an actual fall, counteracting the product's intention. To validate this assumption, a pilot test was conducted researching the effect of the signal on the stride length and overall gait variability, when placed on either location. The effect of the intervention on the MTC was also examined, to preliminarily validate the viability of the main product-idea, see Figure 6.7.

Figure 6.7: The pilot test setup.

Experimental research

iii) Treadmill test - effect of the intervention

6.3.1 Objectives

The objectives of this pilot research were, firstly, to study the effect of the intervention (and its duration) on the MTC parameter, when positioned on either location. Secondly, to investigate whether the effect of the intervention impairs other gait parameters, destabilizing the normal locomotion.

Research question:
Does the intervention have a significant effect on the MinTC height of an individual, when positioned on either location?

H_0 = The intervention has no effect on the MTC height, meaning, the individual's MTC height after an administered signal does not significantly differ from the MTC height before (during normal locomotion).
H_1 = The intervention has an effect on the MTC height, meaning, the individual's MTC height after an administered signal is significantly higher than before (during normal locomotion).

Additionally, the effect of the intervention on the stride length and the MaxTC height was researched, to validate the assumption of the startle response.

6.3.2 Method

Participants
Six young adults (aged 24-26, 3 female and 3 male) were studied, participant characteristics are presented in Table 6.1. All participants were free of conditions impairing normal locomotion, as determined from a self-reported intake questionnaire. To enable positioning of the intervention-prototype, the participants wore socks during the treadmill walking.

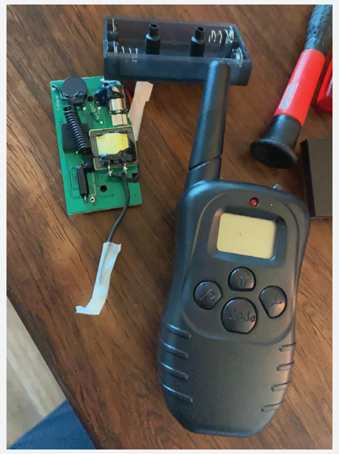


Figure 6.8: The prototype used

The prototype
The vibration was administered through a remote controlled prototype, a customized dog's training collar (Electronic Dog Training Collar by Petrainer, model 998D), see Figure 6.8. A 3D-printed housing made sure the hardware was protected and correctly positioned on the wearer's skin. After preparatory initial testing on both places on the body, an optimal setting was selected, one that was clearly felt, though, not too intrusive or vehement. Level 15/100 was used, the corresponding frequency in Hz is not known.

Gender	Age	Height (cm)	Placement of the intervention	Self-selected walking speed (km/h)	Average MinTC during benchmark (mm)
V	25	166	arch medial of the foot	4.2	14
M	25	190	arch medial of the foot	3.6	20
V	26	173	arch medial of the foot	2.6	21
M	26	198	top of the wrist	3.5	20
M	26	182	top of the wrist	2.4	21
V	24	1.63	top of the wrist	3.1	11

Table 6.1: Participants' characteristics.

Experimental set-up and procedure

After introducing the participants to the test, an intake questionnaire was conducted. Consequently, the participants were fitted with the prototype, by taping the home-made prototype to the predetermined locations, see Table 6.1. Three of the young adults wore it on the arch medial of their foot, making sure it would impair their walk as little as possible: most convenient and least restricting. The remaining three participants wore it on the outside of their wrist. The participants were acclimated to the signal by trying out the prototype while walking through the room. A second batch of questions was asked regarding this sensation and self-reported effects on their locomotion.

In line with similar research in the field, conducted by Begg (2007) and Khandoker (2008), each participant selected his or her desired walking speed, reflecting how they would normally walk on the street. During the experiment, a video displaying a Stroop Test (Stroop, 1935) was showcased to distract the test subjects from the test setup and, hence, to ensure the most natural locomotion.

Each participant's MTC data was collected for two minutes of steady-state walking at the self-selected speed. During the first minute of the test, no intervention signals were administered, to set a benchmark of each individual' normal gait pattern. After that first minute had passed, the signal was administered once, independent of the quality of the test subject's gait at that specific moment. Consequently, the signal was administered at times when the MinTC appeared to decline, when the effect of the signal appeared to fade, as determined with the naked eye. Therefore, the number of administered signals vary per test subject.

After the two minutes had passed, the treadmill was shut down and the prototype was removed. The participants were asked a third batch of questions regarding their performance and their experience with the prototype. The more detailed test procedure can be found in Table 6.2, on the right.

Data collection

The participants' MTC data was collected using an iPhone 11 (720p HD with 25fps) positioned on an elevation. Standard guidelines for 2D filming were followed, as proposed by Bartlett (1992). The smartphone recording unobstructed treadmill walking was positioned 1 m away from the treadmill, perpendicular to the plane of treadmill belt motion. A piece of tape (with a length of 0.5 m) was attached to the treadmill as a distance calibration.

Data analysis

The media collected was analysed in the software tool Tracker (version 5.1.5, 2020). For the analysis, the first 30 seconds of each test were disregarded (half of the benchmarking minute) resulting in an analysis of MTC of 90 seconds for every test subject. In his study, Begg (2007) set up a geometric model, using marker positions and shoe dimensions, to predict the lowest point on the shoe (PTP), see Figure 6.9. In agreement to this, in every frame, the MTC-displacement was manually selected, as indicated. The vertical and horizontal displacement of the MTC was plotted over time. This enabled the extraction of data on the toe clearance parameters (minimum toe clearance (MinTC) or toe-off and maximum toe clearance (MaxTC) or toe-kick), stride length parameter (toe-kick minus toe-off) and overall variability within. A paired-samples t-test was conducted using the SPSS software program, version 25 (IBM Corp., 2017), to evaluate the effect of the intervention on the MTC- and other gait parameters. For this, the data on the five strides prior to- and after an intervention were compared.

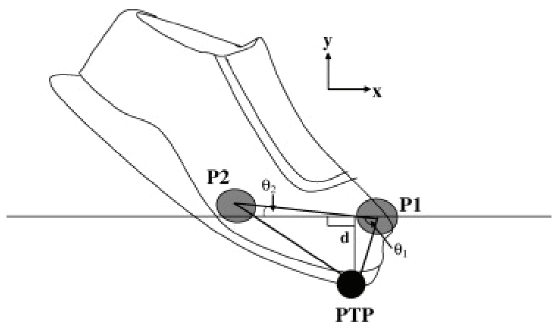


Figure 6.9: The lowest point of the shoe (PTP) during walking, as studied by Begg (2007).

Table 6.2: Complete test procedure.

Part	What	How
Introduction	Introduction of the project and corresponding test	A one-minute presentation of the graduation project and the test setup. Main message: when you feel the vibration signal during the test, you have to remember to lift your feet, in a natural way.
	Intake questions	*- Participant characteristics (gender, age) - On average, how many hours do you walk per week? (options in hours per day) - Do you have any feet abnormalities I should know of? (open answer) - To what extent do you find yourself shuffling during your normal locomotion on a normal day? (1-7)*
The prototype	Placement of the prototype	The participants are fitted with the prototype by taping the home-made prototype to the predetermined locations, three times on the right foot and three times on the right wrist, chosen at random. As the participants' locomotion should stay as normal as possible, the prototype is carefully positioned, most convenient and least restricting to the wearer, repositioning it if necessary. The test subjects wearing the prototype on their wrist are fitted with the same tape around their right foot, to equalize its effects on the participants' gait.
	Try-out of the prototype	While walking on regular flooring, the signal is administered to the test subjects multiple times.
	Questions regarding the signal	*- To what extent do you find yourself walking differently due to the prototype (the tape) placed on your foot? (open answer) - How well do you feel the vibration?(1-7) - What went through your mind when you felt the vibration for the first time? (open answer) - When you felt the vibration for the first time, to what extent do you describe your reaction as a shock-response? (1-7)*
Treadmill	The preferred walking speed	The participants find their preferred walking speed, one that mimics how they would normally walk down the street to the supermarket e.g., by trying out the speeds.
	Placement of the marker	A bright yellow marker is placed near the PTP point on the foot, aiding the manual analysis later on.
	Starting the video on YouTube	A laptop is placed on the treadmill, in front of the test subjects, displaying a YouTube video showcasing the Stroop Test.
Experiment	Walking for 2 minutes on the treadmill, in the participant's preferred speed	Start the treadmill and the video recording. The test subjects walk for two minutes in their self-selected walking speed. They are asked to name the colours they see in the video out loud. The signal is administered at the 1-minute mark, and consequently at times when the MTC appeared to decline, as established with the naked eye.
End	Test ending	The participants shuts down the treadmill and steps off, the marker and prototype are removed. As verification, the participants are asked how many times they have experienced a signal being administered.
	Questions regarding the test	*- Do you think you improved upon the lifting of your feet? (open answer) - To what extent do you find yourself walking differently due to the prototype (the tape) placed on your foot? (1-7) - If you have entered more than 1; can you elaborate? - How well do you feel the vibration? (1-7) - What went through your mind when you felt the vibration for the first time? (open answer). - When you felt the vibration for the first time, to what extent do you describe your emotion as a shock-reaction? (1-7) - To what extent do you think you adjusted your gait after you received the first vibration? (1-7) - If you received multiple vibrations, did you notice a difference between your gait after the first and the last vibration? (open answer) - Did you feel unbalanced when a vibration was given? (1-7) - Do you have anything to share or other things you noticed?*

Table 6.3: Data gathered on the MTC shows the increase in median MTC height and p-value per administered intervention.

			Pre-Intervention (5 strides)		*Post-Intervention (5 strides)*		
Participant	**Intervention placement**	**Intervention no.**	**Min MTC (cm)**	**Median (cm)**	**Min MTC (cm)**	**Median (cm)**	**p-value**
1	foot	1	1.434	1.434	1.457	1.673	0.020
	foot	2	1.038	1.057	1.314	1.636	0.005
	foot	3	1.210	1.477	1.841	1.971	0.005
	foot	4	0.987	1.414	1.936	2.031	0.000
	foot	5	1.509	1.841	1.983	2.363	0.010
2	foot	1	1.630	2.113	2.415	4.227	0.029
	foot	2	3.019	3.683	5.133	5.797	0.001
4	wrist	1	1.736	2.091	1.558	2.031	0.933
	wrist	2	1.910	2.150	1.776	1.954	0.544
5	wrist	1	1.741	2.341	2.371	3.301	0.028
	wrist	2	1.741	2.401	2.401	4.318	0.054
6	wrist	1	0.854	1.037	1.280	1.463	0.056
	wrist	2	1.098	1.280	1.463	1.585	0.286
	wrist	3	1.159	1.402	1.341	1.890	0.459

6.2.3 Results

Figures 6.11 and 6.12 displayed on the following pages, show the vertical and horizontal displacement of the MTC, where the legend explains the markings and symbols applied to the graphs. After each test, the participants were asked how many times they experienced the vibrational signal. Test subject 3 (F, 26, prototype located on the foot) admitted to not feeling any administered signals, meaning the prototype malfunctioned and therefore failed to warn the user. This is clearly visible in the thrid graph from the top, on page 128. Therefore, the data obtained from test subject 3 is disregarded for this analysis.

Effect of the foot-intervention

As for the MinTC height, the effect of the intervention on the foot is statistically significant for all seven administered vibrations, when researching an effect duration of five strides (overall $p < 0.03$), see Table 6.3 and Figure 6.10. Therefore, the null hypothesis can be rejected for when the intervention is placed on the foot. Additionally, the interventions also show to have a positive effect on median MinTC heights, all seven interventions display improvement.

Effect of the wrist-intervention

The effect of the intervention is less evident when placed on the wrist: only two of the seven administered pulses have a significant effect on the MinTC height, for interventions 1 and 2 for test subject 5 ($p < 0.03$ and $p < 0.05$). Five out of seven median MinTC heights have improved, however, three of these effects do not show statistical significance, see Table 6.3.

Effect duration

Considering the intervention's effect duration, the black arrows (see Figure 6.11) roughly indicate for what length of time (in strides) the test subjects memorized to lift their feet, though, open to interpretation. When comparing the effect duration of the intervention between both placements, there is an observable difference. On a group average, the effect duration lasts twice as long when the prototype is placed on the foot. Namely, the average effect duration lasts 10.14 strides when placed on the foot (2 participants) and 5.14 strides when placed on the wrist (3 participants), 71 strides for 7 signals on foot compared to 36 strides for 7 signals on wrist.

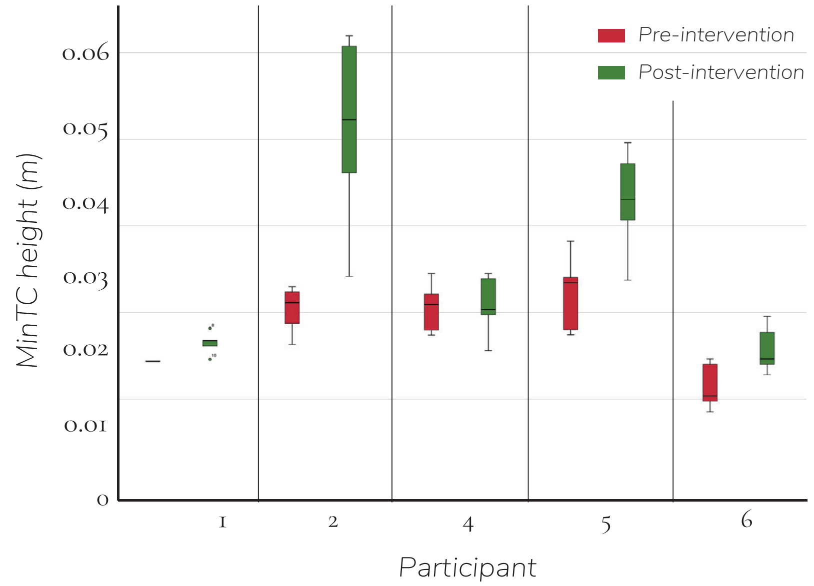
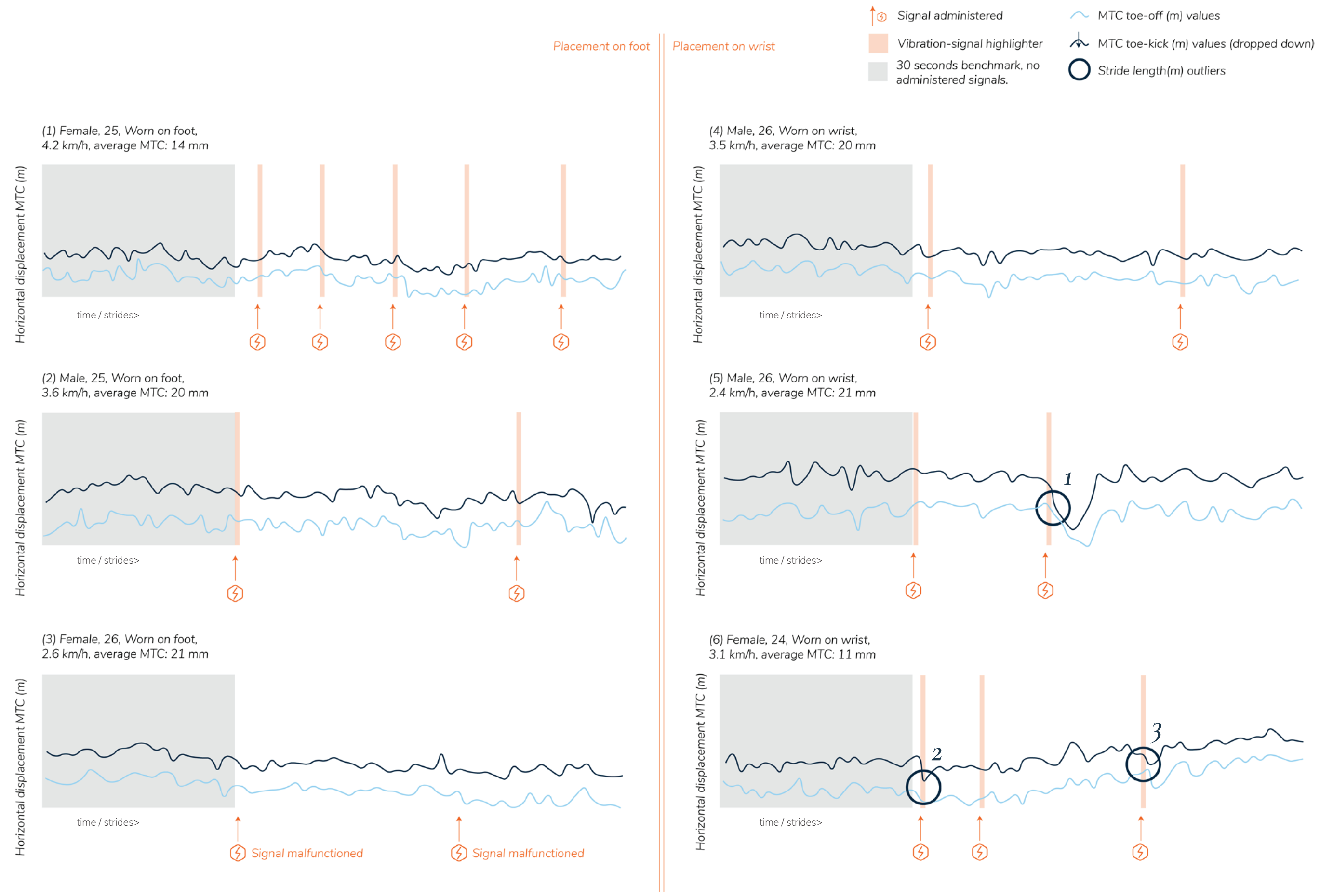


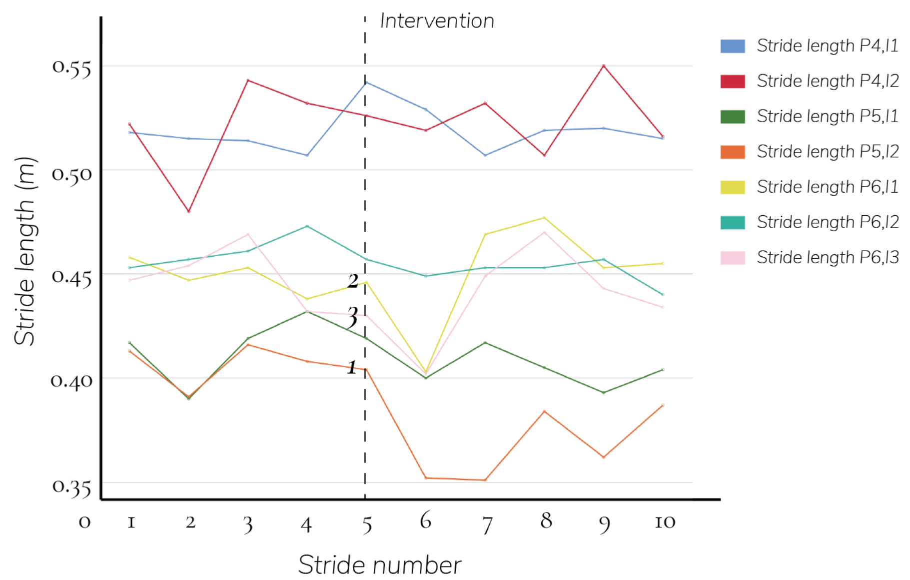
Figure 6.10: Effect of the first intervention on the MTC height, per participant for the first intervention.

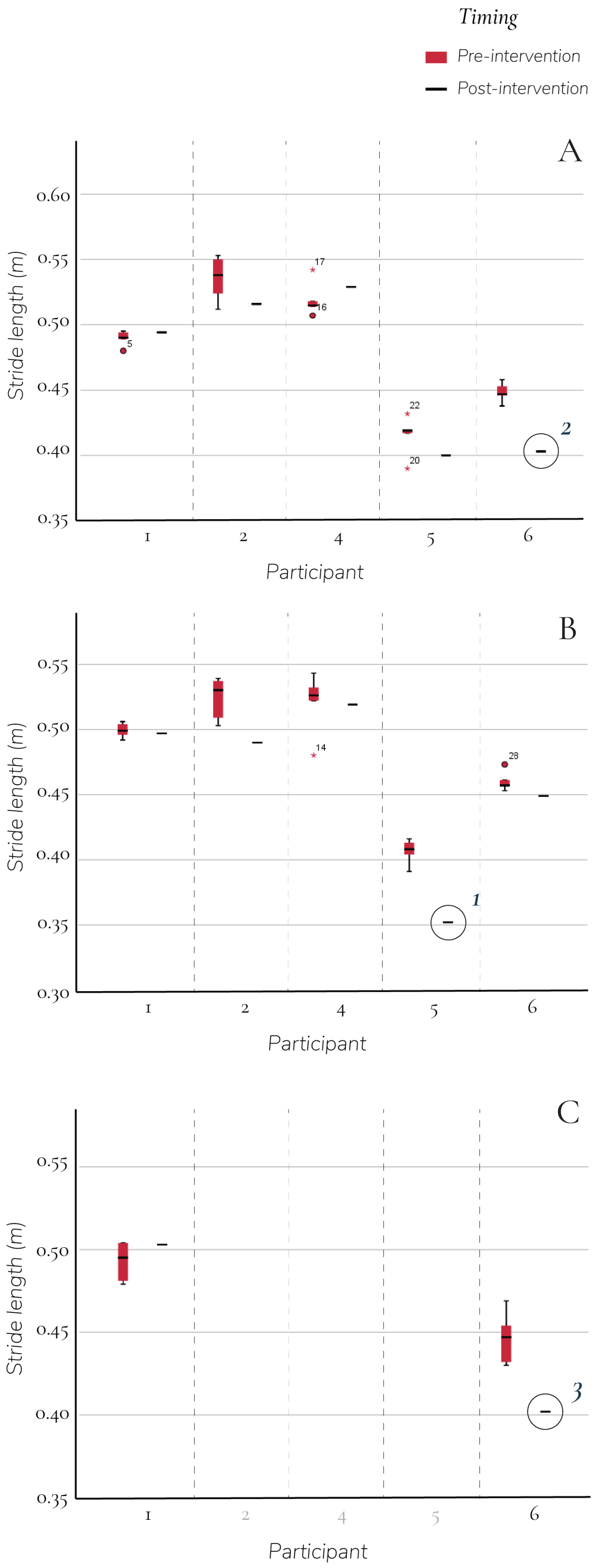


Figures 6.11(left) and 6.12(above): Vertical (left) and horizontal displacement (above) of the MTC for the six test subjects.
The graphs containing the Tracker output data have been added to Appendix 12.

Figure 6.13: The stride length of five strides before and after an administered intervention, when placed on the wrist.

'P' indicates the test subject and 'I' indicates the Intervention number, chronologically ordered.





Figures 6.14-6.16: The difference in stride length before (five strides) and after (one stride) an administered vibration: first (A), second (B) and third (C) intervention.

Outliers 1,2 and 3 are presented in these graphs.

Effect on the toe-kick / MaxTC

Numerous times the MaxTC noticeably increases at the exact moment a vibration-signal is administered, for the length of one stride. This effect only lasts one stride and this so-called toe-kick outlier is indicated by the dark-blue circles in the Figure 6.11. This effect is more prevalent when the administered signal is placed on the foot (5 out of 7 times, against 2 for the wrist).

Effect on the stride length

To study the effect of the intervention on other gait parameters, the horizontal displacement of the MTC was outputted. Hence, data on each individual's stride length could be extracted. The effect of the intervention on this parameter is researched, as an impaired stride length has proven to be one of the gait characteristics leading to a possible future fall, see chapter 2.2.2. To roughly estimate the effect on this parameter, the toe-off values (light-blue line) were subtracted from the toe-kick values (dark-blue line), resembling a stride, see Figure 6.12.

When neglecting participants 4's data, as the intervention does not show any effect on the MTC parameters, three out of five times when a signal is administered to the wrist, an apparent response is visible. At those moments, the stride length is compensated for, for at least one stride. This effect is not observable when the prototype is placed on the foot. These drawbacks are visible in Figures 6.12 and 6.13 indicated by '*1*', '*2*' and '*3*', and in the box-plots presented in Figures 6.14-6.16.

		Intake question
Placement of the intervention	Participant	To what extent do you find yourself shuffling during your normal locomotion on a normal day?
foot	1	3
	2	5
	3	3
wrist	4	1
	5	3
	6	5

Insights from the questionnaire

Besides the statistical analysis of the effect of the intervention based on the gathered data, an analysis on the insights from the questionnaires was conducted as well. Before, during and after the test, the test subjects were asked numerous questions, of which most requested answers ranging from 1-7, 'low' to 'high', depending on the context, see Table 6.4.

The participants' own assessment on their normal locomotion, regarding a shuffling gait, does not conform to the participants' measured average MinTC values. Before, and during the experiment, all participants indicated to feel the vibration sufficiently (> 5). The participants wearing the intervention on their foot experienced a less distinct signal during treadmill walking as opposed to before, in contrast to the other group.

Shock responses to the intervention are relatively low (1-2) and are independent of activity. However, the participants receiving the intervention on their foot indicated to feel a little more out of balance. Also, this group gave the prototype's comfort a lower average score than the group wearing it on their wrist, as they were afraid to push it off with their other foot.

The participants' reflections on whether they improved their gait, with regard to lifting their feet more, match the data obtained from the motion analysis. The greater results achieved by the participants wearing the foot-prototype (significant effect) reflect their self-assessment, the reponses to the questionnaire can be found in Appendix A11.

Table 6.4: Quantative answers to the questionnaires, where '1' means lowest/ least and '7' means highest/most.

Questions asked after testing out the prototype		Questions asked after conducting the experiment				
How well do you feel the vibration?	When you felt the vibration for the first time, to what extent do you describe your reaction as a shock- response?	To what extent do you find yourself walking differently due to the prototype (the tape) placed on your foot?	How well do you feel the vibration?	When you felt the vibration for the first time, to what extent do you describe your emotion as a shock-reaction?	To what extent do you think you adjusted your gait after you received the first vibration?	Did you feel unbalanced when an intervention-signal was administered?
6	1	5	5	1	6	2
6	2	3	5	2	7	2
6	1	1	-	-	-	-
6	1	1	7	1	2	1
5	1	3	5	1	5	1
6	1	1	7	1	5	1

6.2.4 Discussion

Firstly, numerous assumptions have been made when making the necessary decisions to determine the experimental setup. Using the Strooper Test as a method of distracting the participants, as well as the duration of treadmill walking, the exact positioning and application of the prototype on both skin sites, the strength of the signal applied, and the 'manual' application of it, are all important variables that had to be determined. Although these variables were not determined arbitrarily, they could, however, have a direct effect on the data produced. Due to the significant lack of comparable experimental setups meaning this experiment is a first of its kind, there is little data with which to corroborate not only the findings, but also the experiment.

Most importantly, young adults were used for this study, as the method of testing presents too high a risk for the intended age demographic. Due to this, the results may be skewed in such a way that the comparison drawn between the young and the elderly population groups cannot be completely reliable. The effect of the intervention may be significantly different in the elderly populations, thereby rendering the data gathered inapplicable. The conclusions drawn hereafter are therefore tentative, and cannot be applied directly to the intended demographic for this research project.

In addition, it should also be noted that only 6 test subjects were recruited for this experimental research to analyse the effect of the intervention aiding falls prevention. However, the prototype administering the intervention malfunctioned for test subject 3 (foot-intervention), meaning only five sets of data could be used.

Additionally, no statistical analysis could be conducted for the effect on the MaxTC and stride length parameters, as due to the nature of this experiment, the limited sampling data does not allow for such analysis. This leads to rough estimations and imprecisions with regard to these variables. All test setup implementations should be reconsidered when conducting a follow-up test, explained in further sections.

Effect of the intervention on the MinTC

When placed on the arch medial of the foot, the effect of the intervention on the MinTC was statistically significant for all seven applied signals (overall $p<0.03$). This means that the null-hypothesis can be rejected for when the signal is applied to the foot. However, when placed on the wrist, the intervention's effect only proves to be significant for two of the seven administered signals ($p<0.05$).

In response to the three possible strategies to minimize the risk of a trip, proposed by Begg (2007) in chapter 2.3.3, the median MinTC height was analysed. The median MinTC height in the five strides prior to, and the five strides following an intervention were compared, see Table 6.3. The data demonstrates increased median MinTC heights for four of the five participants, with the exception of test subject 4 (wrist-intervention). Regarding the seven foot-interventions, all seven median MinTC heights improved and the effects are significant. According to these results, the suggested placement of the intervention should be on the arch medial of the foot. The other two strategies of reducing MTC variability and skewness and kurtosis, as proposed by Begg, could not be tested for, due to the nature of the experiment.

Duration of the effect on the MinTC

The effect of the intervention is not only significantly greater when placed on the foot. On average, administered on this skin site, the intervention's effect also seems to persist longer. It is assumed that this could be related to the signal being applied to the specific body part that needs adjusting. Receiving sensory input to a specific body part causes the muscles to retract at that region. This event might elongate the duration of the effect. Future studies should look into this.

Effect of the intervention on the MaxTC

At first, the MaxTC/toe-kick outliers, as represented by the blue circles in Figure 6.11 (vertical displacement graphs), were a reason for concern. They could depict a possible startle response, unacceptable for this study. This striking effect was discussed with Dr. Shanty Sterke. She indicated that this is probably related to the retraction of the muscles, due to the startle response. Essentially, Dr. Sterke did not mark these outliers as worrisome, as it does not indicate a momentary loss of balance. However, there is little exact knowledge regarding this striking response of an increased toe-kick. Due to the unreliable and possibly high-risk effect, extensive research on this is therefore crucial to understand the full effect of the foot-intervention on the locomotion of a person.

Four of the five test subjects (excluding participant 3) showcased an overall lower MaxTC average after the signal had been applied for the first time. It is assumed that the heightened focus on the MinTC induces a decrease in MaxTC, whilst the MinTC is increased. Namely, it seems as if the test subjects reduced the fluctuations in their MTC displacement over time. However, at this moment, this development and the possible effect of it on a person's locomotion is not explicable and should be researched in future studies.

Whereas the variability in the MaxTC appears to decrease for test subjects 1 and 4, after the first intervention, it noticeably increases for test subjects 2, 5 and 6 throughout the remaining test duration. Due to the nature of the experiment, this is to be expected. Therefore, this development will not be elaborated upon.

Effect of the intervention on the stride length

The stride length is resembled by subtracting the toe-off (MinTC) values from the toe-kick (MaxTC) values of the same stride. This is not a correct representation of stride length, see chapter 1.2.2, as for this, the toe should be placed on the ground for both measurements. However, due to the continuous displacement of the treadmill belt and the assumption that the foot settlement for each stride can be considered approximately equal, the toe-kick represents the point of toe-contact. Therefore, for this study's analysis, the MaxTC minus the MinTC resembles a stride.

When comparing both placements, roughly half of the time the stride length was distinctively compromised, when the signal was placed on the wrist. This striking effect lasts 1 stride and is characterized in Figures 6.12-6.16. Dr. Shanty Sterke expressed that this reaction is worrisome, as it portrays a momentary loss of balance. The test subject's startle response may indicate uncertainty, which is undesirable. An impaired stride length has also been proven to be one of the gait characteristics leading to a possible future fall, therefore jeopardizing the safety of the intervention. The exact essence of this effect is unknown and should be researched in future studies.

As previously indicated, the calculation of the stride length can be considered an approximation rather than a precise measurement, due to the effect of the treadmill motion on the secondary displacement of the MTC. In future research, improved techniques of calculating gait parameters like these need to be implemented to correctly assess the effect of the intervention.

Test setup - *Prototype*
The aim was for the prototype to not impair the normal locomotion of the wearer, when wearing it on the foot. Hence, the test subjects who wore the prototype on their wrist also wore an attachment-strap to their feet, in an attempt to balance out the effect. However, the test subjects wearing the prototype on their feet gave the comfort of wearing it a lower average score than the group wearing it on their wrist. Participant 1 admitted to being hindered by the product's placement. She indicated that she felt like it impaired her gait a little, as she was afraid to push the prototype off with their other foot. However, as the apparatus should be positioned in the shoe, participant 1 indicated that this would resolve the matter. The participants wearing the prototype on their wrist did not feel any inconvenience.

The selected frequency of the vibration (Level 15/100) was preferred in a small-scale pilot test, and it was administered to both places. The test subjects indicated to feel the vibration sufficiently, though, the signal's clarity was reduced during treadmill walking, when placed on the foot. This calls for more research into the optimal frequency, one that is clearly present when walking, while not being too intrusive or vehement.

Additionally, the signal was manually applied to the test subjects, using a remote controller. As the interventions were administered at times when the MinTC appeared to decline, as determined with the naked eye, the correcting interventions were fabricated. This could have very well affected the test subjects' benevolence to correctly respond to the signal. It could explain the exceptionally high values of the MinTC for test subject 2 and 5, for example.

As indicated earlier, the prototype malfunctioned during the test with test subject 3. This malfunction could be due to the unreliable nature of the prototype. In future tests, the prototype should go through several iteration phases to avoid this issue.

Test setup - *Footwear*
The participants were asked to wear socks during the experiment, to enable utilization of the intervention. During the second experimental pilot test, see chapter 2.4 ii), results showed that footwear has a substantial effect on the MTC parameter. It was not studied how walking on bare feet affects the MTC parameters, as opposed to wearing footwear. However, there is a likelihood that there is an effect. The final product is a smart system embedded in an insole, for which the user must wear some kind of footwear. Therefore, the effect of the intervention must be studied again, for which the test subjects need to wear their preferred footwear, affecting the functional requirements of the prototype.

Test setup - *Treadmill*
Measuring the MTC parameters during treadmill walking constrains and manipulates velocity, as it is kept at a constant speed. This does not represent overground walking and, therefore, it influences the obtained data. However, walking in the real world often elevates task demand as a result of navigating fluctuating heights and materials. This challenges effective analysis of the MTC. Hence, analysing the effect of the intervention using a treadmill in a controlled laboratory environment, as is presented in this research, is less complex and permits more precise measurement.

Test setup - *Method of distraction*
Due to limited time and resources, the distraction-element (the Strooper test displayed on a laptop) was placed on the treadmill, slightly to the right of the participant. Given its skewed positioning, participant 2 indicated that he felt like this affected his gait a little. Also, participant 1 and 6 acknowledged that the tool was a little too distracting at times, since they felt the urge to do well, while also walking properly. Whether the Strooper test is a valid method to distract the participants from the test setup is therefore unclear. It cannot be considered completely reliable to work effectively for each participant. Other methods should be explored in further research, if distraction techniques are deemed necessary.

Test setup - *Camera*
It was decided to collect the data using a camera that captures 25fps. This can greatly influence the quality of the gait assessment, as the exact required moments (the absolute MinTC or MaxTC values) could be missed during analysis. In future studies, more research should be done into the optimal frame rate, shutter speed and other requirements for acquiring data for motion analysis.

6.2.5 Conclusions

The effect of the intervention is clearly illustrated in the data gathered in this pilot test. The effect of the intervention on the MTC parameters, significant when placed on the foot, therefore showcases the validation of the intervention-product. It seems to be an appropriate tool to optimize the toe clearance parameters in the pursuit for strategies of falls prevention. This experiment suggests that the intervention should be placed on the foot, as its effect is significant and shows a more prolonged duration.

Additionally, startle response effects of the intervention were examined by analysing the effect it has on the toe clearance parameters and the stride length (and thereby stride time). As the wrist-placement has an impairing effect on the stride length, it would seem as if this intervention's placement is worrisome. This conclusion was encouraged by Dr. Shanty Sterke. For now, the MaxTC outliers do not characterize as worrisome and are therefore deemed acceptable for the context of this experimental research.

Considering the foot-placement already had multiple superior functional and aesthetic characteristics (superior desirability through level of comfort, unobtrusiveness and usability e.g.) when compared to the wrist-placement, the results from this test are conclusive, indicating that the foot is the optimal placement for the device.

6.2.6 Main insights and concept-iteration

Through conducting the experimental test with the use of a treadmill, it was concluded that the intervention should be administered to the foot. More specifically, supported by research, it should be administered to the arch medial of the foot. This means that the vibration motor, which transfers the signal, can be integrated in the smart insole as well. Therefore, the whole smart system, including the intervention, is embedded in the smart insole, see Figure 6.17.

Additionally, now that the first two segments (detect + warn) of the concept-idea are both positioned in the same product-item, the product is not segmented and this positively affects the ease of use. All technology necessary to monitor the user's gait and convey the signal of a possible impending trip is embedded in the smart insole. Hence, the user will only have to insert the insole in his/her pair of footwear for usage of the product.

Integrating a haptic feedback in the insole is not a new concept in falls prevention strategies. Namely, research as shown that randomly vibrating insoles could alleviate age-related impairments in balance control (Priplata et al., 2013). However, the form of vibration stimulus in research segment is rather different. Here, they generally make use of white or subsensory noise that generates mechanical vibration noise to stimulate the user's feet (Wei et al., 2012) (Galica, 2009).

An intervention-type stimulus, such like the smart insoles generate in this project, seems to be new to the scientific world, with regard to falls prevention strategies. Therefore, all possible risks that this unique product might bring along have not been studied.

Additional to the unknown exact (side) effects of this unfamiliar type of stimulus on a person's gait, there are numerous other attributes to the intervention that need further research. These will be further elaborated upon in Chapter 7.1

Through conducting interviews with health professionals, see Chapter 3.3, it was concluded that a sole invention targeting the MTC is not enough. It should be supported with concrete advice on sufficient and safe exercise in order to postpone or prevent a next intervention. This will be facilitated by an accessory mobile application, see Chapter 6.4.

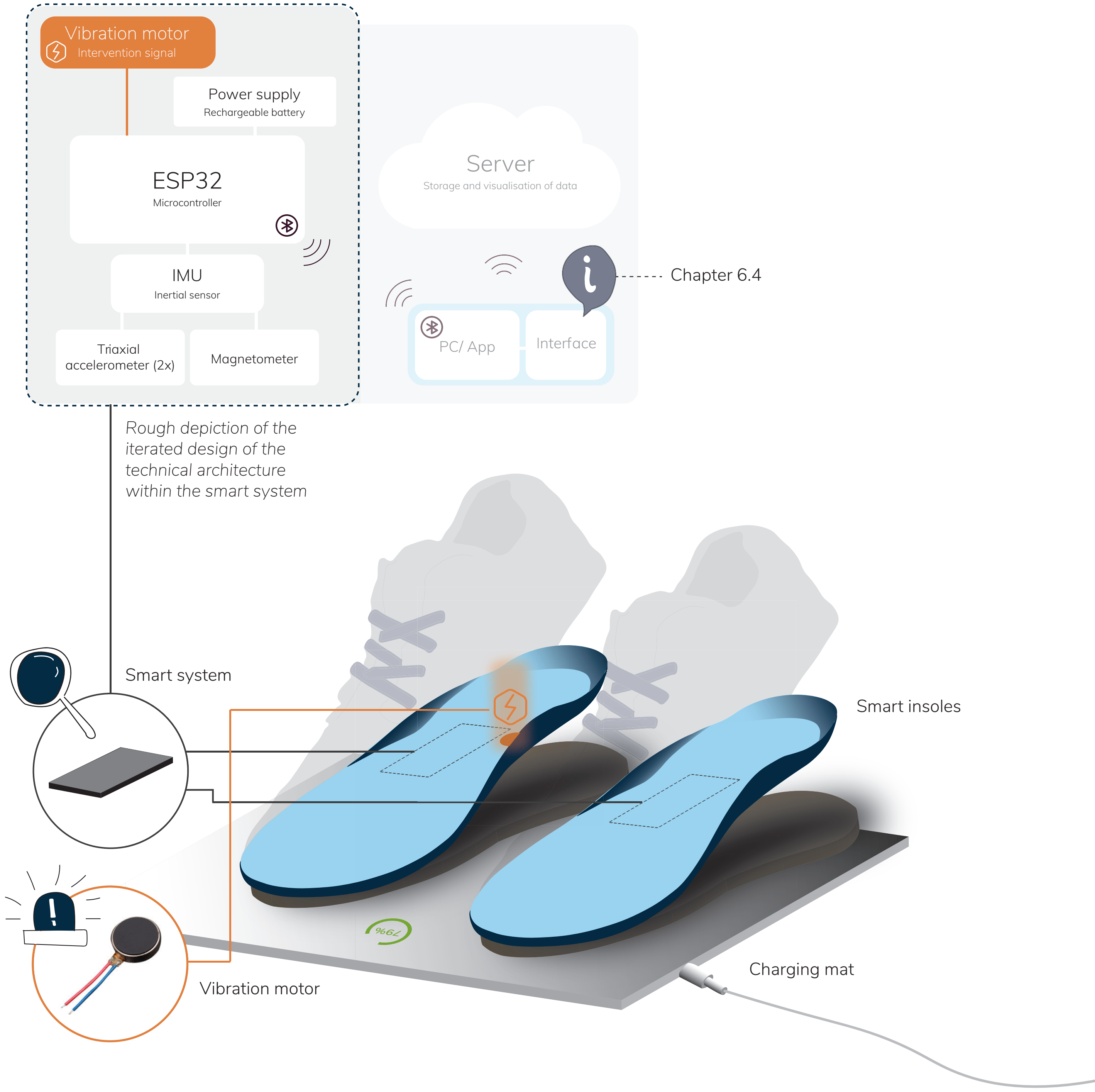


Figure 6.17: The concept-idea of the smart insoles with integrated intevention signal (the vibration motor)

6.4 Signalling pt. 2 - Inform

Insights gained from the expert interviews concluded that a stand-alone warning signal, such as the intervention, is not going to be sufficient on its own. The alert should be supported by a secondary signal, to be provided by a mobile application (service). Statistics concerning the user's interventions and their individual progress, as well information regarding other crucial gait parameters (to avoid a false sense of security) , displayed visibly on the app, are crucial to provide the user with the necessary feedback to ensure their walking behaviour is adjusted accordingly and sustainably.

For the informing / educating signal (secondary signalling) numerous stand-alone technological devices were researched (see Chapter 3.1.2). It was found that most wearable products related to health are assisted by User Interfaces, such as smartwatches, apps and fitness-trackers. Research conducted on existing products related to fall prevention or detection (Chapter 3.1.4) also showed that most of these smart products are also supported through an accessory user interface.

For this project's concept, the app or secondary signal, see Figure 6.18, is focused on informing as well as educating the user on how to improve their gait correctly. It supports the intervention by providing additional info regarding their MTC and other gait parameters. This signal will be outputted when risk encountered throughout a period of time is memorized, with the intention to inform the user of this risk, and of how they could avoid this risk in the future. This secondary signal will present itself in the form of a mobile application, providing the elderly user with the necessary feedback.

Insights regarding the development of the mobile application were gained through additional research and preliminary explorations during the creative session, depicted in Chapter 3.2. Namely, when developing user-friendly mobile apps for engaging the elderly in their health monitoring process, a user-centric approach is essential. For the sensor data to be meaningful to the user, it must be displayed in a clear and accessible way. Research has shown that providing the user with a large amount of raw sensor data could lead to cognitive overload and user discouragement (Rajagopalan, 2017). Therefore, the design of the mobile app supporting the smart insoles should adopt a user-centric approach. The feedback from the elderly users should be solicited and incorporated at various stages in the design process. This will ensure user adaptation and a sustainable behavioural change, see Chapter 3.5.1.

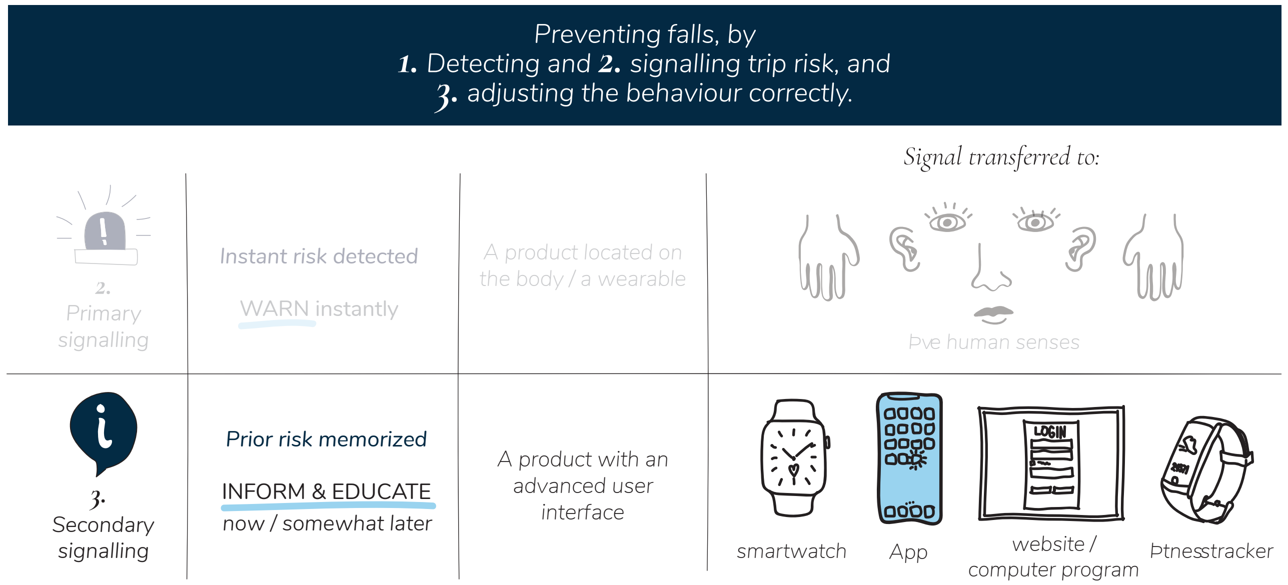


Figure 6.18: The product's two 'stages' of signalling. In this chapter, the secondary signalling will be further explored.

Creative session

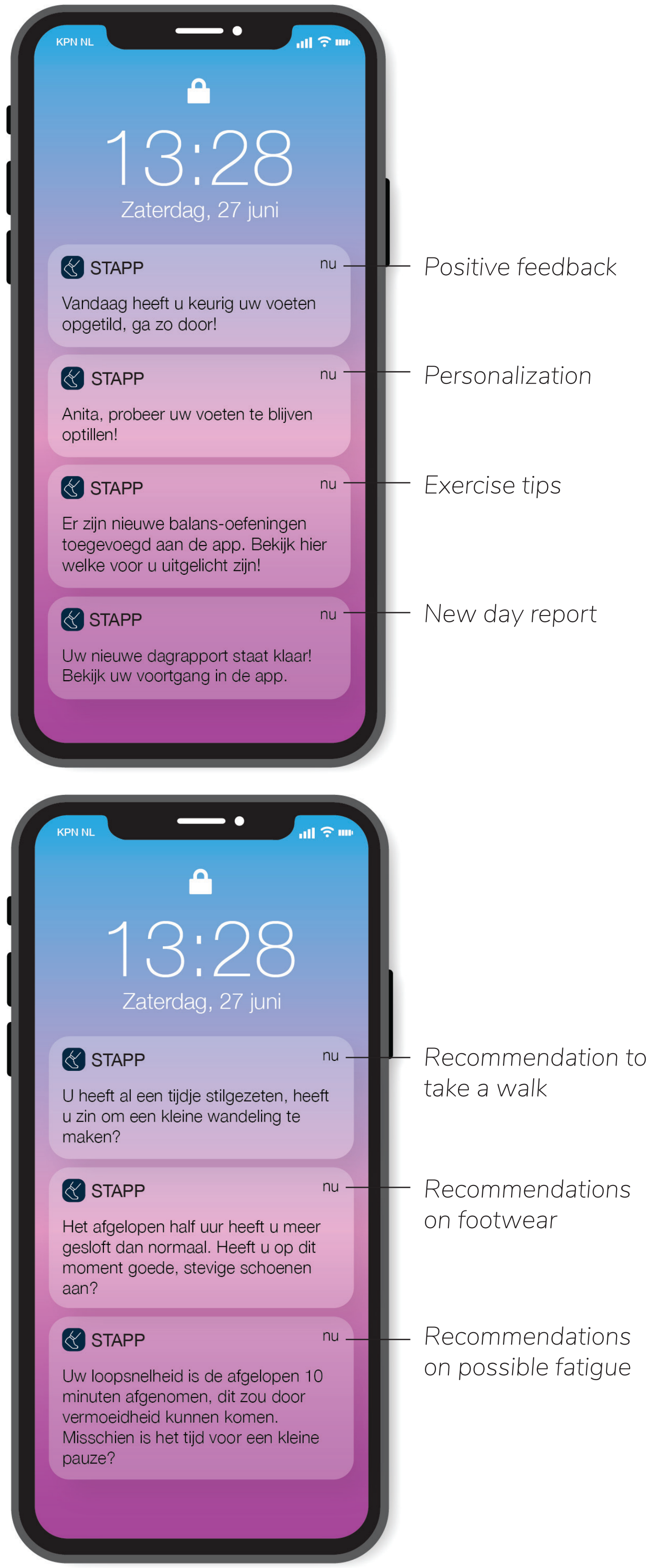
Earlier on in the project, the first step in this user-centric approach was taken during the focus group sessions. General first insights were gained on what the users' needs and wishes are regarding the content of the mobile application. As the explorations took place in the early stages of the project's design process, the elderly evaluated various mobile home screens solely showcasing notifications from the app. This enabled the users to get a general idea of what the app could contain and what it might be signalling to them, see Figure 6.19.

Insights

Six of the eight participants indicated that they would like to receive notifications telling them to lift their feet a little higher throughout the week. Small nudges towards the desired behaviour would aid them in their progress. Personalizing this nudge, by letting the app speak directly to the user by including the user's name, will reinforce this. Additionally, it could be concluded that positive stimulation would work well for the elderly, as it keeps them motivated over a longer period of time.

The elderly showed interest in understanding their progress over time, therefore a weekly or monthly report would be very valuable to them. A few participants also liked the idea of the mobile application including various balance and walking exercises, which could support their current exercise activities. However, similar to how the two personas showed a different ability and motivational profile, other participants solely want to optimize their gait through the MTC parameter. Therefore, there are differences in how the elderly want to use the app. This should be tended to in design of the UI, enabling the possibility to adjust the degree of displayed information.

Figure 6.19: Home screens showcasing imaginable notifications, used in the creative session, portrayed in Chapter 3.3.



Features preferred most were translated into additional user requirements. Together with the general user needs presented in Chapter 4.3, and the functional requirements that are aimed at wearable adaptation presented in Chapter 3.5.3, a List of Requirements was constructed. Through additional research into the design of user interfaces for the elderly, various guidelines were obtained (Duval et al., 2010). Generally, the app should be highly practical (the right amount of information), have excellent readability (font size, usage of contrast, distinction between parts), use language which is easy to understand and read (font style, usage of icons), include large(r) buttons and maintains consistent throughout (all design elements).

Product Experience Map

In order to present a concept version of the UI, all previously described insights are translated into a list of overarching user goals. Accessory user objectives are transformed into segmented needs, subsequently, leading to the necessary UI components. This so-called Product Experience ap therefore contains a checklist of all UI components needed to be represented in the design of a mobile application, see Figure 6.20.

Figure 6.20: The Product Experience Map.

GOALS	USER OBJECTIVES	NEEDS	COMPONENTS
To limit the risk of a fall	Looking for the status of their MTC parameter	Having enough inventory at all times	• A visual overview of their average MTC-value(s) displayed on the app's main screen • A specific segment with a visual overview of the progress of the MTC value, over the last week, month or year • Notification that a new week/month report has been finalized • Statistics on the number of interventions (intervention-history) - Amount of interventions, Date and time etc. • An alert when a high-risk gait is detected (related to MTC or other gait parameters) (Notifying the user to contact the GP or physician as soon as possible) • Fall detection alert sent out to family and/or physician
	Looking for stimulation, reminders to improve their MTC / to lift their feet higher	The ability to receive notifications / reminders to pay attention to their MTC	• Occasional notifications telling the user to remember to lift their feet
	Looking for information on his/her other gait parameters	Information on one's overall gait pattern	• A visual overview of the status of numerous other gait parameters - Gait speed, Gait variability (symmetry), Stride length and time, Step length and time, Step width, etc.
			• (Being able to understand the information): A week, month and/or year report or overview on the progress of their efforts.
	Looking for personalized tips on how to improve upon their gait (pattern)	Being able to receive notifications with tips or training exercises about how to improve upon their gait pattern	• Notifications on how to optimize the status of their gait - Gait speed, Gait variability (symmetry), Stride length and time, Step length and time, Step width, etc.
		The possibility to create a profile / register as a user	• A register-form after installation of the app, containing: - Name, Age, Gender, Length, Type of shoes, Activity-level
			• A log-in option when opening the App

GOALS	USER OBJECTIVES	NEEDS	COMPONENTS
To improve overall balance	Looking for balance exercises	A specific segment with (easy-to-perform) balance exercises	• Balance exercises including: - Sit-to-stand exercise, Weight shifting, Knee lifts, Tiptoe balancing, etc.
		Being able to plan a simple balance exercise schedule to stay motivated	• A balance schedule that notifies the user when they have planned the exercise and a button to verify whether it has been performed
			• The possibility to witness progress in the agenda
		Being able to receive notifications / reminders to perform (small) balance exercises	• Notifications to perform small exercises
			• Notifications when new exercises have been added to the database
	Looking for digital stimulation / support to optimize their balance	Motivational support regarding their performance	• Notifications with motivational prompts
To be more active	Looking for information regarding their achieved amount of daily activity	Insights into their daily activity	• Pedometer function, 'Calories burned', Active time, Walking distance covered
	Looking for information on recommended walking exercises	A specific segment with a training schedule on walking exercises, related to their current activity-level	• A segment containing walking exercises. Starting at a small walk of 5 min. - more elaborate walks
			• Option to indicate the current level of activity when registering
	Looking for digital stimulation / support to be more active	Being able to receive notifications / reminders to take a short walk	• Notifications with the intent to stimulate the user to take a short walk
			• The option to collect small digital rewards to stay motivated
To use the device properly	Looking to use their purchased product	The option to pair the smart insoles with the user's app	• The option to pair their purchased smart insoles in the app
	Looking for information on how to properly operate the product	A small description of the product's working	• Overall properties of the product (visual overview)
			• Instructional video of the product's working
		The option to see the battery status of the insoles	• Battery status of the insoles (preferably clearly visible and easily found within the app)
	Looking for the settings, to adjust it to their preferences	A specific segment with all settings	• Settings regarding - Their account, The app itself (set goals, reminders, exercise schedule), Privacy, Data and synchronizing, Debugging (FAQ sheet), etc.
	Looking for the option to turn off the smart insoles	The option to turn off the smart insoles	• A hidden away button to turn off the smart insoles (in special occasions)

StApp's UI design

The wireframes give a visual representation of how the 'StApp'-application could look like, based on the Product Experience Map. Two slightly different versions of the product-service system have been made. The UI presented down below, in Figure 6.21, is somewhat easier to use (larger buttons and simplified user interaction) and aimed at the older elderly. The wireframes presented in Appendix A13 following present-day UI guidelines are rather similar to existing apps the elderly might already be using (i.e. WhatsApp). Hence, this version is meant for the somewhat younger elderly.

On the right, the registration process is depicted, including all necessary steps to enable personalized use of the smart insoles., see Figure 6.22.

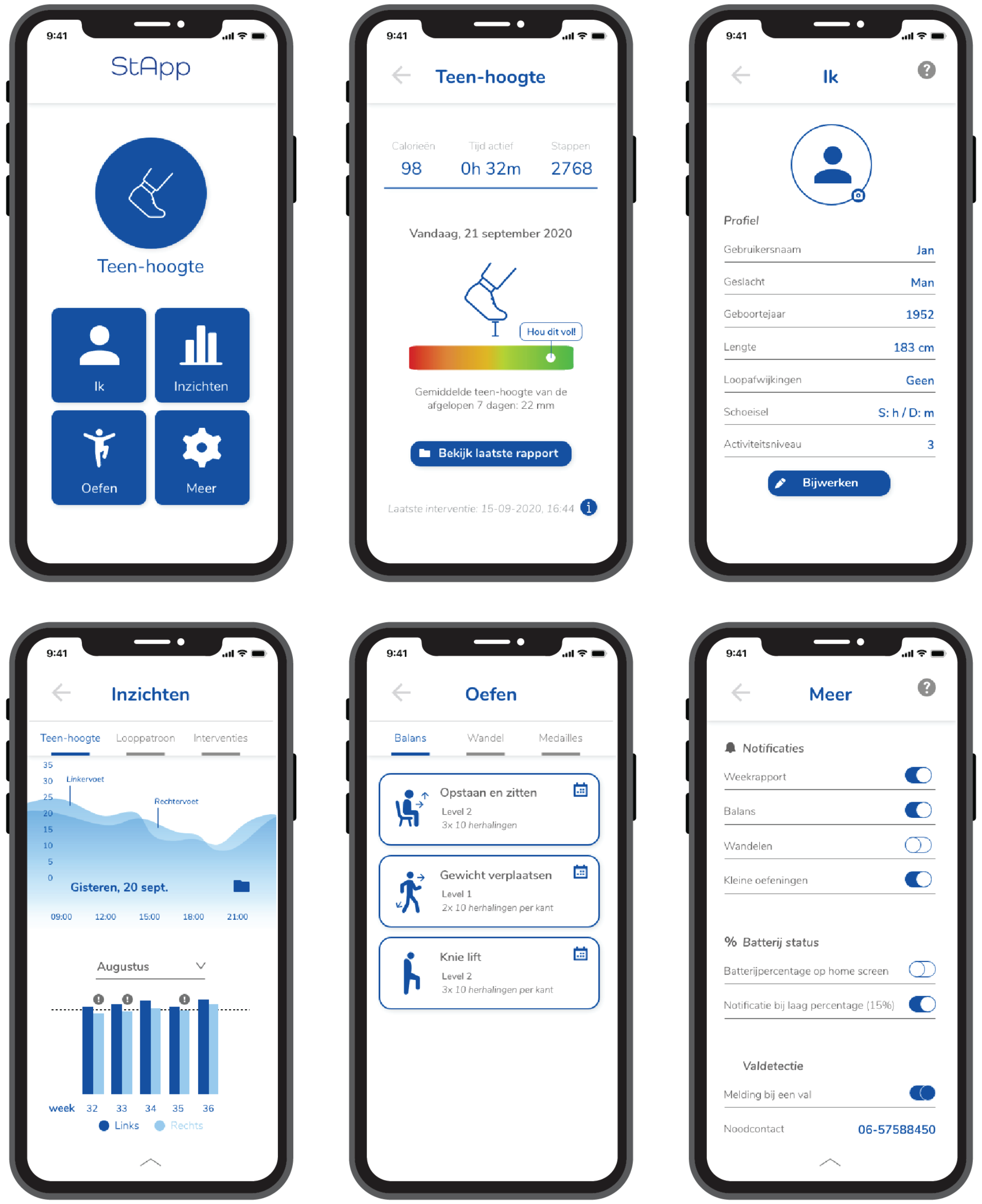


Figure 6.21: An visual representation of how the UI design of the StApp could look like.

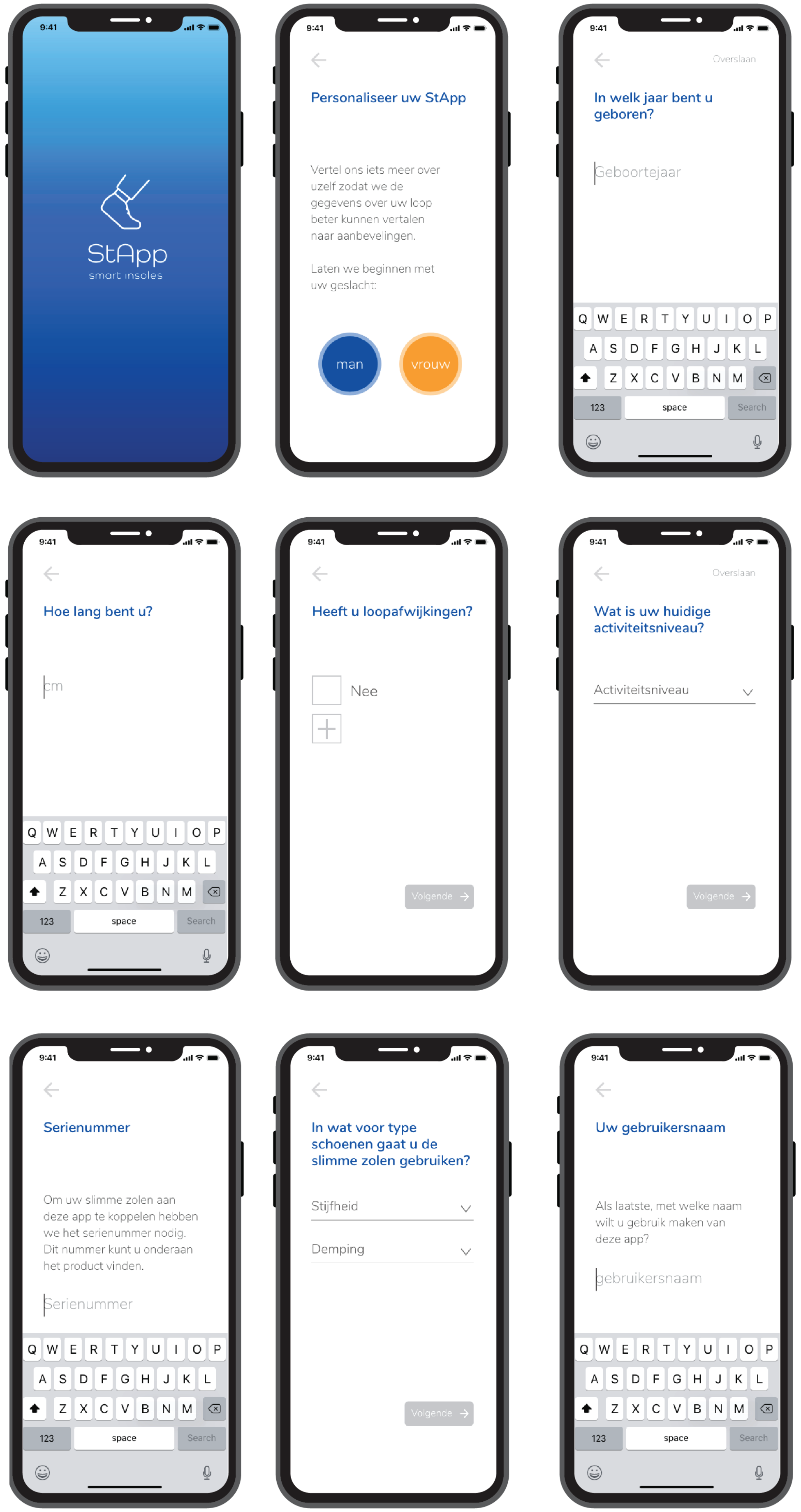


Figure 6.22: An visual representation of how the registration process within the StApp could look like.

chapter 7

Guidelines for Conceptualization

Guidelines for further conceptualization of the smart insole and the UI are presented in this chapter, aiding future research and design studies.

In this chapter:

Smart insoles
Haptic feedback
Product service system

Smart insoles

Effective fall prevention systems must capture the multifactorial nature of falls for reliable risk estimation. Besides the physiological risk factors impairing balance and gait, all other intrinsic and extrinsic risk factors should be included. Most studies state that targeted multifactorial interventions are more effective than interventions aiming to change one risk factor alone. Hence, in order for the smart insoles to have the appropriate effect of limiting falls risk in the elderly, the focus of the MTC should be supported with the right framework. The smart system should be able to identify all scenarios surrounding fall-related events.

As the proposed smart insole consists of a smart system (with vibrational stimulus) it must be studied whether the technological architecture can be embedded in the product. Through brief research into the measurements of existing regular and orthotic insoles lead to the assumption that the framework could be embedded in an insole. However, knowledge of the necessary smart system's measurement is scarce and further research is required.

Additionally, the processing of inertial sensor data is not free of challenges, and their use in real-world conditions require special attention to their capacity and limitations. Namely, the challenges lie in processing of the data and the limitations of the system. Inertial sensors are a powerful tool, though, they need to be used correctly. The accuracy and precision of the data obtained is very important (GaitUp SA, 2020).

Therefore, it is recommended to start off by making a functional prototype of the insoles, including the required sensing technology. The depiction of the technical architecture presented in Chapter 3.1 is merely a simple overview of what the insoles should roughly contain. Research should be conducted in what exact components are required and the framework in which they operate. Consequently, to correctly process the raw data, steps must be undertaken in pre-processing and data-transformation into a frame that makes sense (GaitUp SA,2020)

Subsequently, through testing this design in an experimental study, similar to the experiment depicted in Chapter 6.3, the obtained data could be compared with the output in motion analysis software tools. Hence, the accuracy of the system can be validated, the most crucial part of the design. It should be studied whether the smart insoles are able to accurately characterize the motion of the MTC- and other gait variables, without impairing the user's normal locomotion.

Besides avoiding affecting the normal locomotion of the user, it must be research how the comfort of the smart shoe can be most optimal. Comfort of wearable sensing devices is highly important in fall prediction systems since it entails long-term continuous use. Hence, the insole should be manufactured of a supportive and pleasant material. Cork and leather were discarded due to limitation of production techniques, see Chapter 6.1.2, thereby, foam and gel prototypes should be used. Further functional requirements related to the material should be studied, for example the need for a product as light as possible.

To enable long time monitoring of the gait, it must be studied whether the characteristics of rechargeable batteries can offer enough power. For now, it was assumed that the smart system should be able to generate data for a minimum of 2.5 hours per day. However, research must be conducted into the activity levels of the target age group and whether this number sustains.

Haptic feedback

In this graduation project, the final intervention designed aims to alert the user through a vibrational stimulus. Administering pulses or vibrations to the user as a type of feedback is not a new concept in research into fall prevention. Vibrotactile feedback placed on the torso has been used to improve rehabilitation in individuals with balance problems and noise-based devices, such as randomly vibrating insoles, could ameliorate age-related impairments in balance control. However, the type of stimulus designed in this project has different purposes. Research into the effect of placing a haptic feedback device on the foot to optimize the MTC parameter is of high importance. If the vibrational stimulus is deemed effective an efficient, the optimal intensity and rhythm, among others, should be determined as well.

In the experimental study, vibrational stimulus was applied to the right side of the user's body (right wrist and right foot). Generally, this is the dominant side of a person and it was therefore used in the study. However, the psychological effects of sensing the vibration on one side should be studied, as well as the effect it has on both legs / feet. In the experimental research portrayed in Chapter 6.3, this was quickly evaluated through analysing the MTC of the left foot for the participants receiving the intervention on their right foot. Slight differences were portrayed, though inconclusive. A future, similar, study should analyse whether a single-side-intervention accurately optimizes the MTC- and other gait parameters of both the individuals' legs. If not, further studies should be conducted on the application of the signal.

Accessory to the application, the exact placement must be studied as well. Through research, it was found that the arch medial of the foot is an area most sensitive to the touch. Hence, the intervention should be clearly felt. However, whether this sensitive skin side leads to side effects, such as destabilizing the user or provoke shock, should be further researched.

If the smart insole were to be made out of gel, it must be studied how the vibrational stimulus is passed / bounced through the material. As the gel works well for shock absorption, it could aid or cancel out the intervention, see Chapter 6.1.2. Rapid prototypes of gel and foam insoles, solely containing the vibration motor should create clarity in this matter.

Mobile application

Since the first studies looking at pathological gait solutions in the 1970s, researchers and clinicians were restricted to laboratory conditions to study gait (Gait Up SA, 2020). Since 2000, sensing technology offers new opportunities in the world of motion science and enable health professionals to measure gait for both routine assessment and impactful studies. However, the concept of the smart insoles seems to be a new approach, as it is targeted at the end-user.

Hence, the information provision of the product should be made so to fit the target audience. The elderly must be able to operate the smart insole and accessory app by themselves. Therefore, the mobile application should clearly present information regarding the analysed parameters, though, also on correctly operating the product and how to interpret the data visualized. A study into the necessary UI and UX requirements needs to be conducted, in order to facilitate the kind of interaction that was portrayed in 5.2.2. The future work should also focus on testing the usability and acceptability of the mobile app among the target audience. Usability testing should assess the technical effectiveness and efficiency of tasks within the app (Rajagopalan, 2017).

As the product is aimed at behavioural change, it must be studied how to keep the elderly engaged into lifting their feet and, thereby, prolong use of the device. A study indicates that 32% of users stop using wearables sensors after six months and 50% after a year (Rajagopalan, 2017). Therefore, the research must be aimed at investigating the characteristics of wearable systems, such as its obtrusiveness, cost, and user-friendliness, in order to increase their appeal and user adaptation among older adults. The self-efficacy theory could be used to enhance their level of motivation (Rajagopalan, 2017).

chapter **8**

Evaluation

The final conclusions and recommendations regarding the project's outcomes.

In this chapter:

8.1 Conclusions
8.2 Recommendations

8.1 Conclusions

This chapter evaluates the final design proposal of the smart insole, the mobile application and its use as a fall prediction system. Throughout the design process, healthcare professionals and members of the target audience were asked to provide feedback on the overall design. Recommendations are given as to what is needed for the further development of the smart insole.

The smart insole as a product

Sensing technology offers new opportunities in the world of motion science, enabling analysis of gait to aid falls prevention strategies and to alleviate the financial and physical burdens associated with the consequences of a fall. This project presents a concept design of smart insoles, supported by a mobile application. In this way, the elderly are more able to achieve prolonged independence, and can pro-actively work on minimizing and postponing the risk of a fall.

The smart insole was developed through a research and experiment oriented design process. This started off with an extensive literature study on the characteristic differences in gait between elderly fallers and non-fallers. Namely, the main purpose of the smart insole is to detect alarming changes in the user's gait in order to prevent a fall from happening.

Although this review of literature did not undertake a very comprehensive search of the literature, as the SCOPUS database was consulted exclusively, it was able to demonstrate a range of characteristic differences in spatio-temporal measures of gait most capable of differentiating an elderly faller from a non faller. In future work, it is highly suggested revising the search strategy used, including more databases, optimizing the selection criteria and overall revising the search strategy to fit the derived focus of this graduation project, the MTC.

Namely, after deliberation with the supervisory team, the minimum toe clearance (MTC) was believed to be the most promising parameter to be used for this project. It is directly related to the event of a trip, the predominant cause of falls during walking. It is a somewhat understudied variable, as it assumed that the methods of extracting the variable are more complex, using sensing technology i.e., as opposed to measuring gait speed with a stopwatch, for example. However, whether there are more factors impairing the presumed limited research in this field should be further studied.

Subsequently, the design goal of this project was:

Design of a concept that prevents falls among elderly (60-75), by real-time monitoring of the user's MTC variable and instant signalling of apparent risk therein, in addition, clarifying this through supportive information and (balance) exercises on a separate UI.

What started with exploring the MTC variable and the proposed strategies to minimize tripping risk, led to an explorative study into theories of persuasive design and user adaptation. Namely, in order for the intervention aiming the MTC to be effective, requires ongoing commitment from the user. Insights derived here, were combined with user insights obtained through hosting a focus group, through applying inclusive design techniques.

The insights derived from the focus group sessions were translated in distinct user needs, shaping the base of the List of Requirements used in the conceptualization of the smart insole, intervention and accessory app.

As the intervention, or warning signal, targets one of the human senses, research was conducted in the five ways the human body receives sensory information. Generally, four of the five senses significantly diminish with age, except for touch. Through also considering the user requirement of a subtle and unobtrusive device, it was decided that the product's warning signal should appeal to the touch. As depicted in the Guidelines for Conceptualization, *Chapter 7*, in order to design an effective, efficient and safe intervention, the vibrational stimulus should be further researched. This graduation project did not allow for extensive prototyping, therefore, it is proposed to research the intervention regarding the frequency and intensity, exact placement and application, and housing material: the matter that will house the smart system and intervention. Additionally, weight of the smart insole plays a role. Various prototypes need to be tested to ascertain the most effective, discreet, comfortable and safe way to signal the user of impending risk.

Through conducting interviews with healthcare professionals it was found that an intervention targeting the MTC is not enough. This focus should be supported with concrete advice on sufficient and safe exercise to improve the MTC variable. Personalized feedback is crucial in order for the elderly to gain knowledge on how to limit the occurrence of the intervention, and hence, the possibility of a trip and fall. Therefore, a design of the mobile application 'StApp' was proposed. The app emerged from combining all UI components established in the Product Experience Map. The insights on user needs were translated into this checklist.

However, due to limited time, the map and the proposed UI could not be evaluated with the target group. Therefore, it is proposed to 'go back to the drawing board', and set up a qualitative research into the exact needs and want from the target group. As the smart insole does not have a user interface, and therefore limits elaborate user experience, the focus on the user's experience with the mobile application weighs extra heavy.

The concept, therefore, shows an interim solution until more research is conducted in the exact capabilities of the smart system, the various characteristics of the insole itself and the intervention and overall design of the user interface.

The target group

Due to the delicate topic of falls afflicting a sensitive target group, the designed components of the concept could not be tested with the intended age demographic. Most importantly, this applied to the evaluation of the effect of the intervention on the user's gait. Young adults were used in this study, as the method of testing presents too high of a risk for the targeted elderly population. Therefore, the results obtained may be skewed in such a way that the comparison drawn between the young and the elderly population groups cannot be completely reliable.

However, other methods were explored in order to include the elderly in the design process as much as possible. The time frame during the hosted creative sessions was spent as effectively as possible. Insights were gained on the target group's feelings towards topics crucial to the design of an effective product. Additionally, a general concept of the smart insole idea was presented to gain insights on user needs related to the product's signalling and the open-mindedness towards such a technological product.

As the product will greatly consist of technological components and products like wearable devices are rather new to the older generation, a learning curve is needed and essential in order for the user to operate the product correctly. As there is a certain old age where this learning curve becomes increasingly shallow, the older elderly were excluded from the target audience. Therefore, the final intended user of the product is the healthy elderly person in the age range of 60-75. However, as it was concluded that the care professional should play an important role in aiding or supplying the older generation with the proposed product, these experts could aid the user's use and adoption of the device. If done correctly, the target audience may be stretched to the older cohort, the older elderly more prone to the risk of a fall and in increased need of a product like the smart insole.

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Master Thesis

Rosan Foppen
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