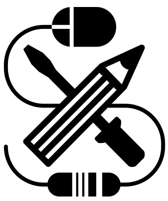
ISABEL PFAB

A WEARABLE INTERVENTION FOR POSTURE IMPROVEMENT



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GRADUATION COMMITTEE

Dr. A. H. Mader
C. J. A. M. Willemse, MSc.
K. Neidlinger, MFA.
B. Klaassen, MSc.
Prof. Dr. D. K. J. Heylen

WEBSITE:
http://www.isa-pfab.com/

E-MAIL:
isabelpfab@gmail.com

ABSTRACT

Incorrect posture is a problem that becomes increasingly wide-spread in today's world. It can lead to short and long term pain in the back and neck areas, and has further been linked to depression. Modern lifestyle facilitates poor posture, especially because of the increasing amount of time people spend sitting. Even individuals that are considered physically active often still spend a considerable amount of time in sedentary behaviours.

Seated posture is therefore critically important and deserves more attention. Typically, people reside in unhealthy hunched-over or slouching positions, especially when interacting with screens. A poor seated posture can also affect a person's posture while standing and walking. Muscle memory plays an important role in this, as the body gets used to being incorrectly positioned. Therefore, to correct ones posture and avoid the aforementioned risks, a correct sitting and standing position has to be established and trained. Wearable technology can be a means to achieve this aim by constantly measuring the wearer's body posture and giving feedback on correct or incorrect posture.

In the course of this project, a concept for a smart garment that can detect incorrect posture and communicate it to the user, who then can correct her posture, is developed. This thesis reports on issues of posture and how to measure it and the applicability of wearable solutions in this context. The novel aspect of our approach is that posture is measured on the front of the body. It is based on the idea that every human has a 'flexpoint', a point where the body bends when one slouches. In other words: it is impossible to have a poor posture and keep the front of the body straight. We confirmed this hypothesis on a sample of 50 participants and then developed an intervention based on it.

The resulting prototype was designed in an iterative process, and a final version was evaluated in terms of its effect on posture. Four participants wore the prototype over a time span of three weeks. It was found that the design clearly has a subjective effect on posture, and an expert also confirmed an objective improvement.
The evaluation further expanded our knowledge about a desirable user experience, leading to suggestions for future design iterations. Overall, the design can be considered to achieve Wearability Level 2: "System is wearable, but changes may be necessary, further investigation is needed". In conclusion, the developed design shows potential, but leaves room for further improvements.

ACKNOWLEDGEMENTS

I would like to express my great appreciation to Angelika Mader, who has been much more than just my daily supervisor. Her support and extraordinarily active involvement have motivated me throughout this project. Without her it would not have been possible. I would like to thank Christian Willemse for taking extensive time to guide me in designing the evaluation study and providing feedback on this report. I am also grateful to Kristin Neidlinger, who has been so kind to let me continuously pick her brain during her stay as artist in residence and has been a great source of inspiration to me. I would further like to thank Bart Klaassen and Dirk Heylen for their advice and assistance. I could not have had a better graduation committee.

Special thanks to all participants in my user studies, especially Khiet Truong, for being the first guinea pig and putting so much thought into providing feedback, and the four lovely ladies who have patiently been wearing the prototypes for several weeks and provided so much helpful insights and suggestions. I greatly appreciate the assistance I have received from awesome professionals in areas I lack expertise, especially in terms of electrical engineering - Loek Gijben and Edwin Dertien - and physiotherapy - Rik Schurink and Matthias Hilgers.

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1 INTRODUCTION

1.1 SETTING

The document at hand describes the execution of a final project for the masters programme Human Media Interaction at the University of Twente, the Netherlands. Human Media Interaction (HMI) is a two-year programme that aims to combine knowledge, technical expertise and skills from a range of disciplines to create interactive systems that automatically respond to a users behaviour, emotions and social cues and make appropriate decisions on what action to take.

During the masters programme I have developed an interest in the topic of wearable technologies and smart garments as a new platform for interesting user experiences. Due to their inherent closeness to the user, these kinds of devices enable new interaction possibilities, as well as more intimate user experiences. Wearables therefore have the potential to overcome limitations of other interfaces in terms of continuous presence and intimacy, especially when it comes to behavioural changes. For these reasons I decided early that I wanted to focus my final project on the development of life-enhancing wearable devices.

The initial idea for this project came from Kristin Neidlinger, founder of Sensoree. The San Francisco based company crafts wearable technology and interactive installations which promote a concept called extimacy - externalized intimacy. On her first visit at the University of Twente, we brainstormed together with Angelika Mader, who has been closely involved in earlier explorations of wearables and is also the daily supervisor for this project, on interesting projects for collaboration. Kristin mentioned the idea of a posture enhancing wearable she had 'lying in the drawer' for a while.

The novel aspect of her approach is that posture is measured on the front of the body. It is based on the idea that every human has a 'flexpoint', a point where the body bends when one slouches. In other words: it is impossible to have a poor posture and keep the front of the body straight. This idea showed potential, but Kristin did not have the time to pursue it further. Since the issue of poor posture is one that concerns myself, it was quickly decided that this would be worth further investigation.

1.2 PROBLEM STATEMENT

There are many factors in modern lifestyle that can be related to causes of poor postures. Especially the increasingly sedentary behaviour, in particular time spent sitting, needs to be mentioned here. Even individuals that meet or exceed the public health guidelines for physical activity often still spend a considerable amount of time in sedentary behaviours.

A recent survey at the Gallery building [1] showed that 66.6% of people sit at their desk for more than six hours a day, 50% even sit more than eight hour. Taking breaks to get up and move are often forgotten as people focus intensely on their work. This kind of behaviour is not specific to the surveyed group, though. With the shift towards a knowledge based society, more and more jobs become sedentary - people sit at a desk the entire workday in front of a computer. Furthermore, extensive sitting often expands into leisure time. On top of all of that sitting at work, people usually sit during meals as well as while commuting in a car or public transport. Once at home, watching television, reading or playing games on the computer or console are popular pastimes that are all performed seated.

Seated posture is therefore critically important and deserves more attention. Typically, people reside in unhealthy hunched-over or slouching positions, especially when interacting with screens. This can be related to seemingly ubiquitous neck and shoulder pain [2], from which 70% of survey participants in the gallery suffer. A poor seated posture can also affect a person's posture while standing and walking.

Postural dysfunction or poor posture has many other negative effects, both physically and mentally. Apart from the aforementioned pain in neck and shoulders, but also the lower back, it has negative influence on internal functioning of the body. Because weight and thus pressure is not optimally distributed over the body, it cannot function properly. This influences breathing, blood flow and digestion.

On the mental side, poor posture and in particular slouching have been linked to depressive disorders [3] and lack of confidence. This in turn influences perception by others and can have serious consequences for career and personal life. Poor posture also results in higher stress levels [4]. It is important to note in this context that posture is not just a passive indicator of mental states, but can reciprocally affect the mental states and behavior of an individual [5].

In our initial exploration of the issue in form of informal conversations with friends and colleagues, two key aspects became clear: first of all, people pay very little attention to posture until they experience the described negative effects. Secondly, people do lack perception of how correct posture even feels. We therefore feel there is a need to increase awareness of ones posture throughout the day and provide guidance on when someone sits in an unhealthy posture.

However, traditional means of monitoring and evaluating posture are time-consuming, expensive, and have proven difficult to implement [6]. Sensing technology can help patients acquire awareness of their posture and correct it when necessary [7]. A wearable device can be particularly useful in this context, as it is location independent and allows for continuous observations as well as real-time feedback.

1.3 RESEARCH QUESTIONS

The starting point for this work, the overall question addressed in this thesis is formulated as: *"How can we design an effective wearable intervention for posture improvement based on the flexpoint hypothesis?"*

There are three distinct aspects following from this question, which need to be addressed in order to find a satisfactory solution. First of all, we want to address issues of posture and how to improve it. To be able to do so, we need to gain an understanding of the topic. The second aspect of the overall question is concerned with designing a wearable device. Finally, once an intervention has been designed, it needs to be evaluated. Evaluation thus forms the third aspect.

1. Posture Questions
   a) What is the ideal human posture?
   b) What types of poor posture are there?
   c) What is the state of the art in measuring posture?
   d) Does the flexpoint hypothesis hold?
      i. Does the flexpoint exist?
      ii. Which types of poor posture can be measured at the flexpoint?
   e) Which type of technology can be used to measure posture at the flexpoint?
2. Design Questions
   a) What are the factors that influence user experience of wearables?
   b) What is a desirable user experience for this project?
      i. Which type of feedback is appropriate?
      ii. Which form factor is appropriate?
   c) What are the design decisions?
3. Evaluation Questions
   a) How to design a user study that evaluates effects on posture?
   b) Does the design have the intended effect on the wearer's posture?

1.4 APPROACH

The overall question addressed in this thesis, which is concerned with the design of a wearable device for posture improvement, can be addressed in many ways. From prior experience, the creative technology design process seems an appropriate approach to address any design question related to wearables, as they fall within the key areas of creative technology products. The creative technology design process has been described by Mader and Eggink [8], who teach in the creative technology bachelor programme at the University of Twente. This approach, which combines user centered design with engineering principles, is shortly outlined in the following. It is also used to provide structure to the remainder of this document.

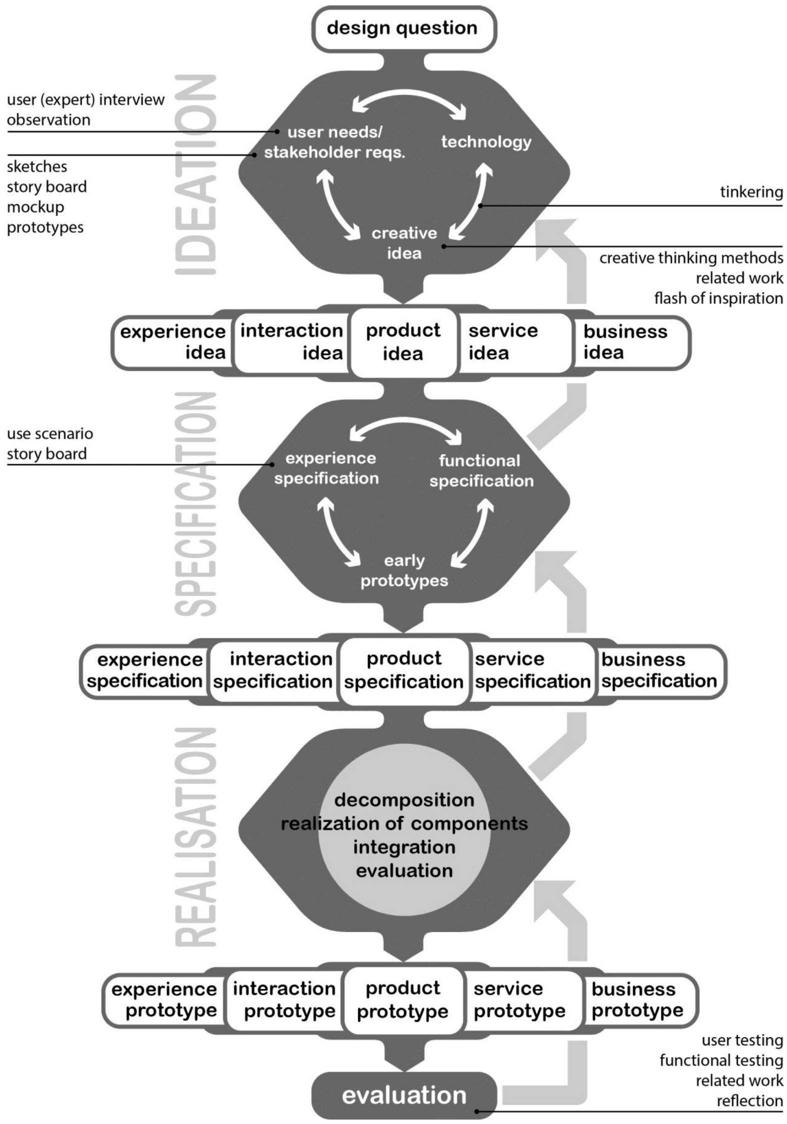


Figure 1: Creative Technology Design Process

Figure 1 illustrates the overall picture: the design process consists of four phases; ideation, specification, realisation and evaluation. The first two phases typically happen in a non-linear manner: the starting point for a project can lay in a creative idea, be rooted in exploration of novel applications for existing technologies (tinkering) or, as in the current case, from a user or stakeholder perspective. Within the ideation phase, all of these aspects should be explored. In this exploration, the design space is first broadened (divergence) and then narrowed (convergence) to generate a defined product idea. In the current work, we separated related work, which is typically part of ideation, into a different chapter to improve the structure of the report. Nevertheless, it has informed the ideation process just as much as expert interviews, sketches, rapid prototyping and flashes of inspiration.

During specification, a series of prototypes is produced and evaluated in terms of functionality and experience. These prototypes may be discarded, improved or merged together. Again, a divergence - convergence process is applied. This phase results in specifications for a final prototype. In this work, we began with a use case scenario and confirmation of the flexpoint hypothesis, before diving into details, such as selection of appropriate sensors and feedback. Based on these decisions, an iterative series of prototypes has been developed and tested.

In the realisation phase, a prototype is developed based on the insights from specification. For a smart garment, this means decomposition into aspects of software, hardware and textile. These are being realised one by one, and then integrated with each other. One peculiarity of this work is that the prototype does not completely conform with all user experience specifications, and is not fully integrated. The electronics can be completely detached from the textile parts. This was necessary to appropriate the prototype for evaluation.

Finally, we evaluate the prototype in a long term study with four participants. For this, we hand out prototypes to them for three weeks of daily wearing. The evaluation covers both functionality - actual improvement of posture - and user experience. The insights from this evaluation serve as a basis for development of future iterations, outside of the scope of the work at hand. The report is concluded by a reflection on the thesis and recommendation for future work.

2 CONTEXT

2.1 WEARABLES

This section addresses Design Question 2a, "What are the factors that influence user experience of wearables?" by means of a literature survey. The identified factors are used throughout this thesis to structure discussions of user experience.

2.1.1 Definition

Wearable technologies pose one of the most promising trends in human media interaction [9]. Utilised in a wide variety of application areas, their most general purpose is to enhance the quality of life. Due to their inherent closeness to the user a whole range of new interaction possibilities is enabled. Therefore, wearable devices could overcome the limitations of current interfaces [10]. They thus have the potential to add value in terms of functionality and performance when compared to other technologies [11].

The terms 'wearable technology', 'wearable devices', and 'wearables' all refer to electronic technologies or computers that are incorporated into items of clothing and accessories which can comfortably be worn on the body [12]. Other definitions add that these technologies mediate their user and their environment [13] and let the user access information anytime and anywhere [14]. In other words, we refer to a worn system that is capable of sensing and communicating with environmental and the wearer's conditions and stimuli [15].

2.1.2 Dimensions of Wearable User Experience

In prior efforts, we have identified five dimensions that shape the user experience of any wearable. These dimensions - area of application, human aspects, wearability, technology and design process - form a suitable framework to discuss the existing work considered, as well as to frame the development of our own prototype. They are outlined in the following paragraphs with respect to the topic of this thesis.

Application areas

The first dimension of wearable user experience we discuss is the area of application. It determines the context of any wearable device, and thus has a high contribution to the user experience. This is the case for human as well as technological factors. Application is even likely to influence the process in which the device is designed. In the present case of a wearable device for posture improvement, there are three possible application areas that could be addressed:

THE SPORT/FITNESS SECTOR promotes an active lifestyle, in which wearables can serve to monitor fitness, navigate outdoors, regulate body temperature as well as measure and optimise sporting performance. One distinguishing aspect of these devices when compared to e.g., wearables for wellness applications is that they are not necessarily worn all the time, but rather for specific activities. Measuring and providing feedback on posture could enable athletes and sportspeople to keep proper form. Examples of sport applications in which posture plays an important role are rowing [16] and strength training, i.e. weight lifting [17].

THE MEDICAL SECTOR includes applications related to professional medical and health care. Wearables can be useful in this sector by providing doctors assistance in diagnosing diseases and monitoring reactions to medication. They are also expected to increase patient mobility by freeing them from bulky machines, e.g., by monitoring vital signs. To use wearables in these applications, they are required to conform to medical equipment regulations that are, for instance, not required in wellness products. A posture enhancing wearable for the medical sector could be relevant for two distinct user groups: on the one hand patients, which experience physiological or psychological issues caused by poor posture, such as structural deformity of the spine or shoulder, back or neck pain [18], or are in rehabilitation [7]. On the other hand, it could assist medical professionals throughout their workday. Especially nurses frequently experience occupational lower back pain.

THE WELLNESS SECTOR aims at a healthy overall lifestyle and general well-being of the wearer. It includes cases for physiological monitoring, weight and energy monitoring, emotion monitoring, eye care, gait/posture correction, massage and sleep monitoring. Wellness related wearables are often worn continuously throughout the day. This sector is particularly interesting for the development of a wearable posture improvement device, as posture has a significant influence on overall well-being [19] and there are less restrictions when compared to the medical sector.

Human Aspects

Human aspects pose the second dimension of wearable user experience we consider. No matter the application area, incorporation of knowledge about the wearer is of major importance for acceptance and thus spreading of wearable technologies [20]. In this section, we look at how wearables can address fundamental human needs, cover factors that influence acceptance like cognitive attitudes, demographic and social aspects, show potential purposes of smart garments and identify peculiarities of usability.

USER NEEDS According to Maslow's revised Hierarchy of Needs (see Figure 2) there are two levels of human needs, basic and meta, along which people constantly strive to move upwards. These needs are deeply entangled in the way people use and adapt technologies. Buenaflor and Hee-Cheol [20] argue that wearables that fulfil the lower level needs are more likely to attract users. Such include smart clothes that have functions such as monitoring sports activity and regulating body temperature which satisfy physiological needs, as well as wearables that provide safety.

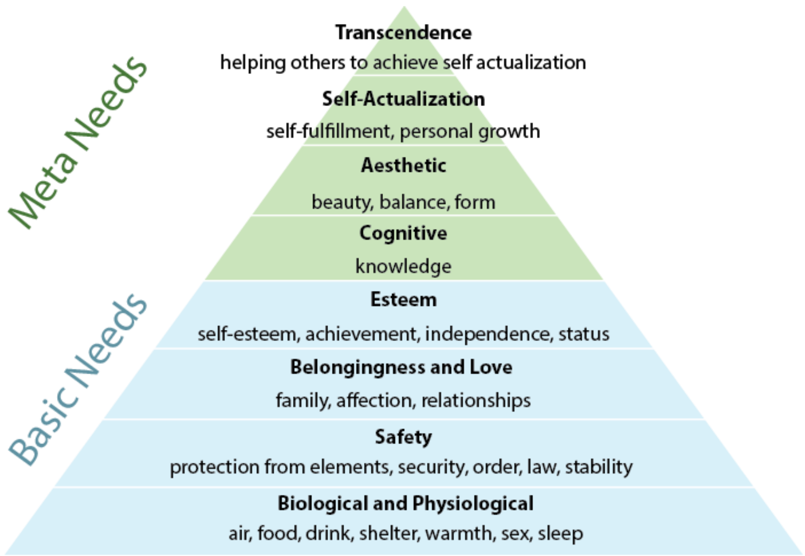


Figure 2: Maslow's Revised Hierarchy of Needs

However, other researchers point out that basic needs are generally fulfilled in the developed world, so people are striving to satisfy higher order meta needs [11]. These include cognitive and aesthetic needs, self-actualisation and self-transcendence. Thus, a transition can be observed from making and marketing a product to developing non-tangible concepts that satisfy the demand of higher order needs, such as ideas, sensory and emotional fulfilment, cultural experiences and entertainment which stimulate the intellect.

We argue that all wearable devices tend to cater meta needs. The vast majority of devices facilitates cognitive needs, in particular knowledge and self-awareness, by collecting information about the wearer and making them accessible. In this manner, self-actualisation can be triggered, as illustrated by the quantified-self movement. Further, the distinguishing factor for wearables, their integration with clothing and jewelry, brings in a responsibility to at least consider aesthetic needs. This of course does not exclude that lower level needs can be addressed. From our observations, different application areas typically relate to different user needs. In particular, medical wearables attend to biological and physiological needs, whereas wellness assumes that lower level needs are already fulfilled and aims at meta-level needs, especially self-actualisation. Sport / fitness combines these two.

COGNITIVE ATTITUDES User perception of a new technology significantly affects acceptance and any negative perception of the device presents a barrier to its adoption. According to the Technology-Acceptance-Model, the two most important cognitive attitudes that influence acceptance of any technology are perceived usefulness and perceived ease of use [21]. The same yields for wearable technologies [20]. Thus, a user must be able to see how a wearable device makes their life easier. Further, usage must be perceived as intuitive or at least easy to learn. Assumed fears - fears based on (wrong) assumptions - and perceived disadvantages are other factors that influence a person's acceptance of smart clothing, especially among women [20].

DEMOGRAPHIC CHARACTERISTICS AND TECHNICAL EXPERIENCE Age and gender are the most influential demographic characteristics when it comes to dealing with any sort of technology. While Buenaflor and Hee-Cheol [20] define technical experience as a separate aspect for technology acceptance, we argue that technical experience is often determined by demographic circumstances and can thus be included here.

Younger people who grew up with computers typically find it easier to adapt to new advancements than elderly. It is an interesting question whether this is also the case for wearable technologies. Especially devices used for monitoring, which do not require additional user interaction besides being worn, might be very suitable for older individuals and other people that have little familiarity with technology. No technical experience is required to attire clothing, a process they are well familiar with.

When it comes to gender, men were found to be more accepting of wearable technology than women [20]. This is also visible in many of the commercially available wearable devices, such as smart watches or fitness tracker bands. Their design can often be considered quite male-oriented. However, there is a movement of fashionable wearables, especially for wellness and glamour applications, which are targeted towards women. In our opinion it is therefore questionable whether these findings are to be generally accepted or whether the wearables used in this study were simply not designed with female users in mind.

SOCIAL ASPECTS Three social aspects were identified as important to acceptance of wearables: social influences, culture and personal privacy [20]. This means that the opinions of one's surroundings shape how a device is perceived, as well as how much personal information is shared.

PURPOSE The functionality of a wearable device is contextual depending on its purpose [22] and application area. Since we are looking at high-level purposes of devices from a human perspective, rather than a functional one, we included this factor in the human aspects rather than the application area dimension. High-level functions of wearable technology have been investigated in PSFK's 'Future of Wearable Tech Report' [23]. By analysing currently available wearable products, they forecast the following key functions of (near) future wearable devices:

- **Support** - Data-Streamed Care manages ones personal health
- **Record** - catalogue ones personal experience to a Cloud Memory
- **Nudge** - Responsive Coaching leads to better behaviour
- Communicate - connected experiences promote Long Distance Togetherness
- Verify - password provided by ones Authenticated Self
- Control - interact with the world through an On-board Interface
- Augment - enhance natural abilities through Augmented Sensory Perception
- Restore - regain movement with the aid of Bespoke Biotech

- Mirror - reflect ones well-being through an Emotional Mirror
- Align - Biometrically attuned systems personalize ones surroundings

The boldfaced items are the purposes a wearable for posture improvement could take on.

USABILITY One of the concerns that consumers often have of new technology products is that they become more difficult to use and adapt to with increased sophistication [11]. Ensuring good usability is therefore one of the main objectives when designing wearable user experiences. Nugroho and Beilharz explain that simplicity is of high importance in creating a user-friendly wearable device, because a user's ability to navigate the device influences the user's engagement, as well as impression of interactivity and responsiveness of the device [22]. Ease of use is also one of the determining factors for technology acceptance [20].

As indicated earlier, we believe that wearables have the potential to become more usable than other technologies, especially for inexperienced users. This of course implies that we consider interaction design for wearables. Interaction, as in the exchange of information between wearer and device, is mainly determined by the chosen input and output modalities. We look in more detail at possible modalities in relation to technologies. Because of the unique relationship between people and their clothing, a new paradigm of interaction possibilities is opened. Yet, it seems that the majority of current products simply adopt mobile interaction design and apply this to wearable devices. This means that the great advantage of wearables, namely being much more connected to a user's physical body than any mobile device, is not utilised.

We propose that usability can be significantly improved when wearables incorporate interaction patterns known from clothing. Many forms of such interactions in which usability is addressed from a garment perspective are imaginable: first, one could use classic garment interfaces such as buttons or zippers. Second, one could use interactions people have with their clothing as basis. For example, there is a project in which pulling down a shirt's sleeves and playing with, a common pacifying behaviour, is used as basis for interaction. The designers extend the calming effect of this action by triggering heating elements in the back and shoulder areas. We consider this as exemplary in terms of ease of use, because the interaction happens naturally to the extent of being subconscious. Moreover, it is possible to move away from focusing solely on the user's hand for interaction. The closeness to the body allows for usage of physiological measurements as input.

Wearability

Wearability is the key dimension that distinguishes the design of wearables from other types of portable technology. It is sometimes considered part of the human aspects, but we decided to make a clear distinction between the two dimensions. In this work, human aspects relate to the psychological and social factors that play a role, whereas wearability relates to physiological aspects. A device that is 'unwearable' (meaning in this context that it causes discomfort or is difficult to wear, not that it is impossible to mount on the body) simply will not be adopted by its user [24], [25], [14]. While examples

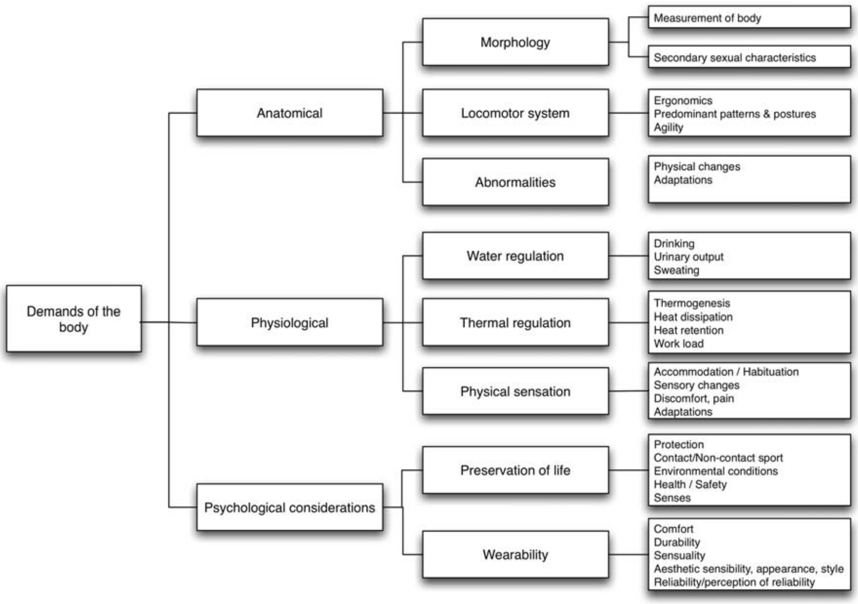


Figure 3: Demands of the body [25]

such as women wearing high heels may render this point to be debatable, it seems obvious that designs should at least not aim to be discomforting to the wearer.

Gemperle et al. [26] were the first to determine thirteen wearability guidelines that have since been widely accepted. These guidelines concern placement on the human body, form language, human movement, proxemics (human perception of space), size variation, attachment, containment, weight, accessibility, sensory interaction, temperature, aesthetics and long-term use. According to [24] wearability includes thermal and moisture management, flexibility, mobility, and durability, with an extra emphasis on sizing and fit.

Bryson [25] highlights the importance of wearability for successful adaptation and acceptance of smart fashion. He classified the 'demands of the body' that should be considered to ensure wearability. He distinguishes between anatomical, physiological and psychological demands, but points out that the inter-relationship between these considerations is highly complex in the design of smart clothing and wearable technology. A complete overview of the demands can be seen in Figure 3. In this classification, wearability consists of comfort, durability, aesthetic considerations, sensuality and (perception of) reliability. Extending his work with insights from further sources, we arrived at three factors that make up the wearability dimension: comfort, durability and aesthetics and fashion. These are outlined in the following paragraphs.

COMFORT is the first aspect mentioned by Bryson [25], and is often considered the most important aspect of wearability. Some authors even go so far as to define wearability as wearable comfort, e.g., [24]. According to Hatch (1993), comfort can be divided into thermophysiological comfort, sensorial or neurophysiological comfort, and body-movement comfort [15].

'Thermophysiological Comfort' relates to the way in which clothing affects heat, moisture, and air transfers as well as the way in which the body interacts with clothing. There are three thermal aspects of designing objects for the body - functional, biological, and perceptual [26]. A proper thermal regulation is necessary to comply with physiological demands of the body [25]. Thermophysiological comfort is one of the aspects where new developments in material sciences, such as new smart textiles can bring major advantages. By changing physical properties of textiles using nanotechnology, functionality that supports thermal regulation can be integrated and provide improved comfort.

'Sensorial or Neurophysiological Comfort' relates to how users feel when clothing comes into contact with the skin, the aspect Bryson calls 'sensuality'. Again, the level of comfort is largely influenced by material choices, but also fit and form language. Sensorial comfort is highly important to user experiences. Because wearables are so close to the body, the 'feel' may become even more important than the 'look'. Sensory evaluation of fabric handle and other tactile properties is of high importance [27]. Stiffness, thickness and smoothness of materials are some of the properties to be considered for neurophysiological comfort.

Further, not all human bodies are the same, but to be comfortable wearables must meet the anatomical demands of each individual wearer's body [24]. While this is the case for regular clothing as well, it is new to the field of electronics. There are two approaches to size variations: either making use of established clothing size systems, or designing a flexible solution that fits all. This can be established by using adjustable or flexible parts. For the same reason, design for the human body requires a humanistic form language [26]. This means taking the wearers body shape into consideration and designing organic shapes. For example forming a concavity on the inside surface touching the body to accept human convexities. The form language is therefore closely related to the location of the wearable on the human body, and relevant to sensorial comfort.

Finally, 'Body-movement Comfort' relates to the ability of clothing to allow free movement, reduce burden, and to support the body. The human body moves at any given point in time due to human activities like breathing or walking. Wearables design must consider movement as a constraint to the shape of the wearable, as it should not hinder movement [26]. Further aspects that can constrain body-movement comfort are placement on the body, weight and attachment to the body, as well as proxemics.

By their very definition, wearables must be attached to the wearer's body in some way. This should ideally happen in an unobtrusive manner. Gemperle et al. [26] recommend wrapping the device around the body, rather than using single point fastening systems such as clips or shoulder straps to create comfortable attachment. They found general body areas that allow unobtrusive attachment of wearable objects to be the collar area, the rear of the upper arm, forearm, rear, side, and front ribcage, waist and hips, thigh, shin, and top of the foot. Most wearable devices currently on the market are worn on the wearer's wrist, thus complying with this guideline.

The weight of a wearable device can heavily influence the level of comfort experienced by the wearer [14]. Apart from individual differences, the location of the device on the body determines the maximum weight that can be attached without hindering movement or increasing the energy cost too much. Proxemics refers to the human perception of space. Wearable devices should stay within the wearers intimate space, so that perceptually they become a part of the body [26]. The intimate space ranges from touching to about 46 cm from the body, thus this limit should not be exceeded.

DURABILITY Wearables must be built to allow long-term use. This refers to both long continuous wearing, which is often limited by power supply, and long-term durability. Clothing should withstand harsh conditions during laundering and everyday use [15], and thus so should wearables. The specific requirements for long-term use depend on the application area of the wearable: both in terms of frequency of use and surrounding conditions. To illustrate, a sports related wearable might only be worn during the sportive activity, thus has a lower frequency of use than a device that is worn continuously. It must however be able to withstand the surrounding conditions, such as release of moisture or heat generated by the body.

Wearables contain electronic and other components that require proper protection from damage to ensure a seamless user experience. These components may also influence the form of the wearable, e.g., by size requirements, and must therefore be considered in the design process. For example, the electronic components of current commercial wearables, like smart watches or fitness trackers are typically tightly contained within a more sturdy material. It, however, results in rigid pieces. This brings us to another aspects of durability for wearables: flexibility. Electronic components are typically rigid and do not withstand bending or flexing, whereas textiles are typically flexible and can be deformed without issues. This naturally creates challenges for creators that need to find a way to combine these two worlds.

Special attention with regards to durability must also be given to wiring and connections. While wires may be flexible, they are often considered the weakest part of any wearable. Therefore, there is considerable work to replace traditional wires with textile-based networks in smart clothing. Techniques include conductive fibers, yarns, fabrics, embroidery, and optical fibers [15]. While some of these approaches may work well for industrially produced devices, the materials available to makers are of questionable durability, so that standard wires are still frequently used.

AESTHETICS AND FASHION Since clothing is a fashion item, there is an identified need for innovative design and fantasy in the creation of fashionable wearables to excite the wearer [28]. Aesthetics can have a strong effect on the acceptance and adoption of clothing, and thus of wearable devices [15]. Though not technically unwearable, devices may be perceived as so ugly by the user that they are psychologically damaging or become objects of derision [25]. As established earlier, we defend the point that all wearables should appeal to the human need for aesthetics.

Aesthetics are closely related to concepts of fashion. It should be noted that the term fashion can have two distinct meanings [29] - fashion as clothing, which refers to the meta need for aesthetics, and fashion as something popular in the sense of trends, which relates more to the wearer's basic need for belongingness. In this thesis, we refer to fashion in the first sense, though it needs to be acknowledged that trends certainly influence the appearance of wearable devices.

Fashion is inextricably implicated in constructions and reconstructions of identity: through appearance style, individuals announce who they are and who they hope to become [30]. This seems to be particularly the case for females. As Woodward puts it: "It is apparent that clothing does not simply reflect the self or identity. Instead, by virtue of being a material form that woman can look at, hold and put on their bodies, clothing gives women a sense that they have a self and indeed that they can change it" [31, p. 157]. The way one dresses is thus a metaphor for identity; this extends to wearable technologies and smart garments as well.

The intersection between wearable technologies and identity is one of the most interesting aspects of the topic. Wearables have the potential to allow expression of identity in new ways, unachievable by regular clothing. This highlights once again the importance of considering the wearer in the design of wearable technologies:

- Who is the person that will wear this device?
- Which identity does the wearer aim to take on? How does this device assist in constructing this identity?

With regards to a posture improvement garment, aesthetics and fashion shape two distinct aspects: first, the design of the garment itself, its form factor and materials. Second, we aim to support the wearer in constructing a more healthy and confident identity by means of a better posture.

MEASURING WEARABILITY One interesting question when it comes to wearability is how to measure or confirm it. According to Knight et al [32], there are five levels of wearability, defined by energy cost, biomechanical effect on the body and comfort. These levels can be found in Table 1. The authors determine energy cost by measuring heart rate and relative perceived exertion. Biomechanical effects on posture, localised pain and discomfort make up the second category. Comfort relates to being 'generally wearable' and not impairing the wearer's vision. While we question whether the proposed measures are exhaustive and always applicable, defining wearability levels can be useful for evaluation. Only products that acquire the first level should be taken to market.

Technology

Technology is the fourth dimension that influences wearable user experience. Progress in technology has been one of the major drivers of the emergence of wearables. Electronics have become smaller, more lightweight and more accessible, thus making truly wearable smart clothing possible in recent years. There are several distinct aspects of technology that play a role in smart clothing. They include integrated circuits, data and energy management, communication and, most importantly for user interaction, input and output interfaces. The following paragraphs outline these factors individually.

Table 1: Levels of Wearability [32]

Wearability Level (WL)	Description
WL 1	System is wearable
WL 2	System is wearable, but changes may be necessary, further investigation is needed
WL 3	System is wearable, but changes are advised, uncomfortable
WL 4	System is not wearable, fatiguing, very uncomfortable
WL 5	System is not wearable, extremely stressful, and potentially harmful

INTEGRATED CIRCUITS AND DATA MANAGEMENT The term 'integrated circuit' describes electronic circuits formed on a small piece of semiconducting material, which perform the same function as a larger circuit made from discrete components. Integrated circuits can function as microprocessor, computer memory, amplifier, oscillator, timer or counter. Integrated circuits are used in virtually all electronic equipment today and have revolutionised the world of electronics due to their low price. They play a key role in wearable technology, as they allow for small-sized components. A particular integrated circuit is categorised as either linear (analog) or digital, depending on its intended application.

There are several specific platforms available that address factors of wearability, such as durability and being washable. These integrated circuit systems typically include microprocessors and sensors. Adafruit's Lilypad, Flora and Gemma microcontrollers are examples of such systems, which are available for rapid prototyping and DIY smart garments. In commercial products, custom integrated circuits are used, optimised for the corresponding functionality of the product. There has further been work on integrated circuits that could be applied directly to the human skin. Cho et al [15] add that active research on textile-based integrated circuits is required to advance the quality and comfort of wearable technology.

The amount of computing power required for a given wearable strongly depends on the type and amount of data collected by the device. The complexity of the required computations also plays an important role here. Designers and engineers should consider different case-specific requirements to make appropriate choices when it comes to data management. Many wearable devices outsource heavy computation to other devices, such as smartphones or the cloud servers. This allows for usage of simpler and cheaper integrated circuits in the device itself, while the user can still benefit from advanced features.

ENERGY MANAGEMENT One of the most persistent issues of wearable technology today is power supply. To be truly wearable, a device must have a sufficiently long battery lifetime. Additionally, power sources should conform with requirements of wearability as established in Section 2.1.2. Most commonly, rechargeable batteries are used for wearables. However, conventional power supply is known to have a short lifetime, as well as being bulky, heavy, and rigid [15]. New developments in energy-harvesting technologies might resolve this issue in the future. When it comes to energy harvesting for wearables, science and industry are currently focusing on solar cells, thermoelectric harvesting and piezoelectric harvesting [33].

COMMUNICATION While there are stand-alone products out there, most wearable devices use a form of communication in the sense of transferring information or power to other devices. Communication can be either short or long range. Short range communication in this context refers to communication between different components of one or more wearables worn by one person. Short range communication can be wired or wireless, using technologies like infrared or Bluetooth. Long range communication refers to communication between several users [15]. Long range communication requires wireless connections. Popular technologies for this purpose include Wi-Fi and the Global System for Mobile communications (GSM).

INTERFACES From a user perspective, interfaces have the most visible impact of all technological factors mentioned. They determine the way the user interacts with the device, and thus often influence the form factor. Interfaces can be distinguished between input and output modalities. Which input and output modalities should be used for a wearable depend on the desired application and functionality: the nature of the task at hand and the information to be managed [34]. Both input and output interfaces of wearables can be classified by the amount of cognitive load they require from the user [34]. The higher the cognitive load, the more attention is required by the user to interface with the device. Different functionalities of a wearable device can necessitate higher or lower cognitive load.

Seymour [35] compiled an extensive list of possible input modalities, which can be found in Table 2. She divides inputs between those originating from the wearer and those from the environment. Cho et al [15] introduce the modalities that can capture these inputs. They address (textile-based) buttons and keyboards, sensors, speech recognition and others. All of these input modalities can be distinguished between active and passive input technologies. Passive input devices collect data unobtrusively without conscious action from the user, and thus in general have a low cognitive load. Buttons and keyboards, by comparison, require active manipulation and attention from the wearer, and thus have a higher cognitive load.

Sensors can cover a broad range of data related to the wearer or the environment. In fact, there are sensors for each of the inputs listed by Seymour [35]. While many wearable devices make use of embedded traditional sensor systems, there are also textile-based sensors, which have the added benefit of being highly comfortable to the wearer. Textile sensors are typically smart fibres that can be directly applied to textiles [35].

Output interfaces present information by stimulating the wearer's senses. Visual, auditory, and tactile interfaces are commonly used in wearable technology, however there are also experiments with scent-based output. As Seymour [35] points out, the options are endless and depend on the project requirements. Table 3 shows output modalities she recommends.

Table 2: Input Interfaces by Origin [35]

Origin	Inputs
Person	pressure bend motion biometric data sound visuals humidity proximity orientation displacement smell acceleration
Environment	light humidity sound temperature smoke micro- particles visual

Table 3: Output Interfaces by Sense [35].

Sense	Output
Visual	LEDs, thermochromic inks, photochromic inks, EL wires, E-ink, (alphanumeric) displays
Sound	speakers, buzzers
Touch	motors/actuators, shape memory alloys, conductive yarns, conductive fabrics
Smell, Taste	scent capsules

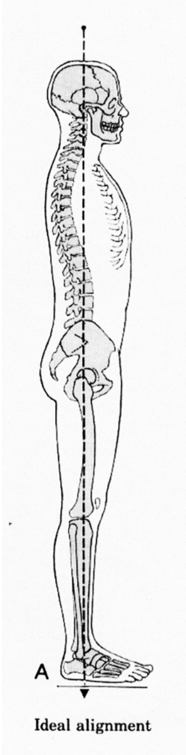


Figure 4: Ideal standing posture

2.2 POSTURE

This section sets out to answer Posture Questions 1a "What is the ideal human posture?" 1b "What types of poor posture are there?" and 1c "What is the state of the art in measuring posture?".

DEFINITION Posture is the mechanical relationship of the parts of the body to each other. It can be divided into static posture (at rest or without anticipated movement, e.g. lying, sitting or standing), and dynamic posture (in action or anticipation of action). It changes with positions and movements of the body, and is influenced by many factors, including general health, sex, body build, strength, personal habits, environment and mood [19].

In 1946, the Posture Committee of the American Orthopedic Association defined good posture as 'that state of muscular and skeletal balance which protects the supporting structures of the body against injury and progressive deformity irrespective of the attitude in which these structures are working and resting. Under these conditions the muscles will function most efficiently and the optimum positions are afforded for the thoracic and abdominal organs'. Another definition emphasises that it aims to 'involve a minimal amount of stress and strain and which is conducive to maximal efficiency in the use of the body' [36].

STANDING POSTURE The ideal human standing posture has been described by Tattersall and Walshaw [19]. They point out the following physiological requirements that must be fulfilled in this ideal state, which can be seen in Figure 4.

1. Forces of gravity are evenly distributed through the body so all joints are in their neutral zone

2. There will be minimal wear and tear on these structures and the natural balance and correct length of muscles is maintained

3. Movement patterns are normal and all vital organs are properly placed, not constricted and therefore can function efficiently

4. The line of gravity passes through a point on a level with and immediately in front of the second sacral vertebra (the centre of gravity).

This means, that when viewed from the side:

- The head is in neutral position
- The spine retains its natural curves
- The pelvis is in neutral, anterior superior iliac spine lies in a parallel line with the posterior superior iliac spine
- The knee joints are in neutral and not hyper extended
- The lower leg is vertical and orthogonal to the sole of the foot

And, when viewed from the front or back:

- The line of gravity should bisect the body into two equal halves with body weight evenly distributed between the feet and the kneecaps face forwards

Figure 5 describes the natural curves of the spine that should be retained in ideal standing posture. Clinical literature described the ideal spinal curvature as a slight lordosis at lumbar and slight kyphosis at the thoracic regions [36].

There are several forms of incorrect posture, in which the spinal curves deviate from the ideals described above. Figure 7 shows three common issues: Kyphosis-Lordosis, flat back and sway-back. All three of them can additionally be acompanied by so-called 'forward head' posture, a dysfunction in which the head is shifted forward compared to a neutral position.

SEATED POSTURE While there is a well-established ideal for standing posture, a consensus on the ideal seated posture is lacking. Textbooks on musculoskeletal assessment are used as a basis for ergonomic advice, but they appear to advocate three different spinal curve combinations. These are described below and can be seen in Figure 8, together with the definitely non-ideal 'slump' or 'slouch' posture.

1. a flat lower thoracic and lumbar posture or a flat lumbar posture with backrest support

2. lordosis at both lower thoracic and lumbar regions (long lordosis)

3. thoracic kyphosis with lumbar lordosis - similar to the ideal standing posture (short lordosis)

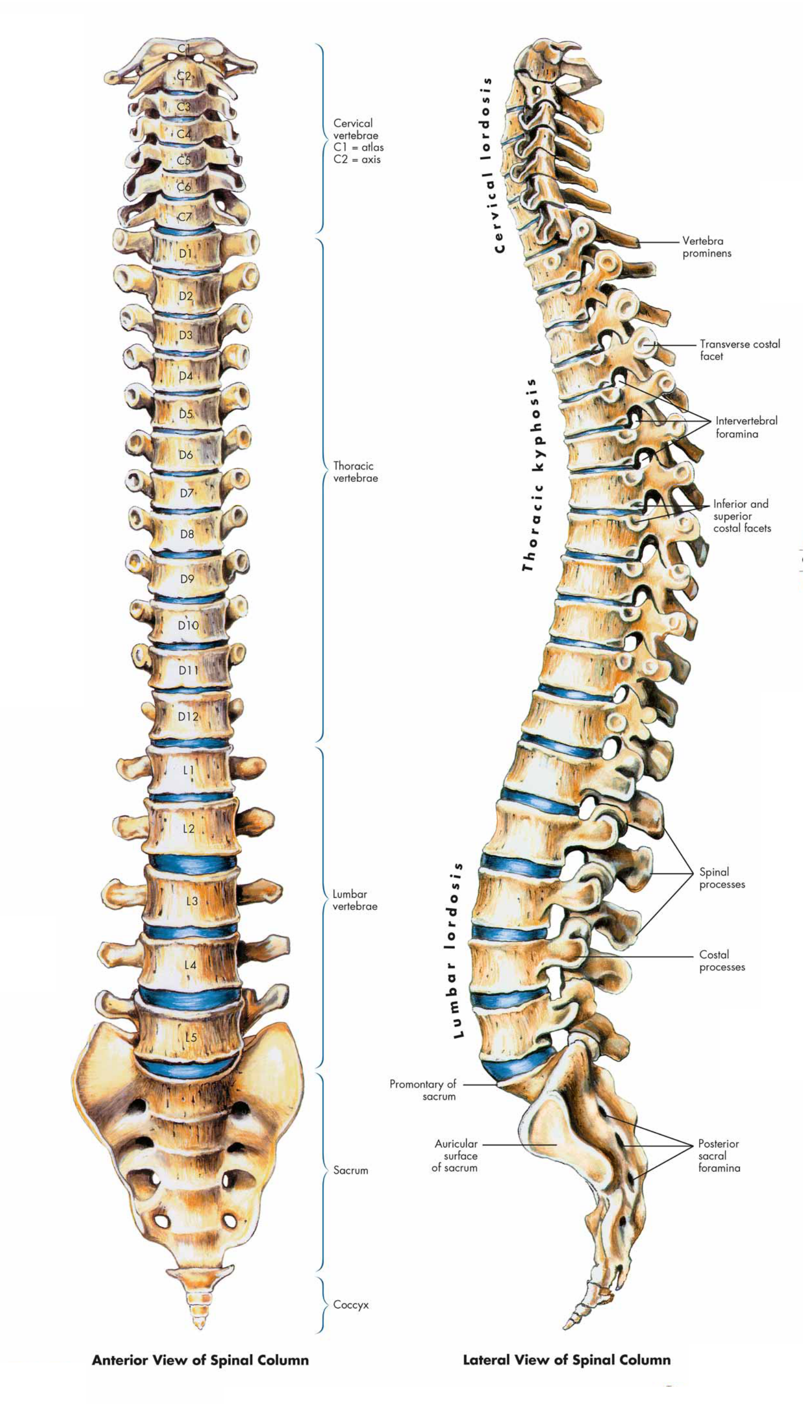


Figure 5: Natural curves of the spine

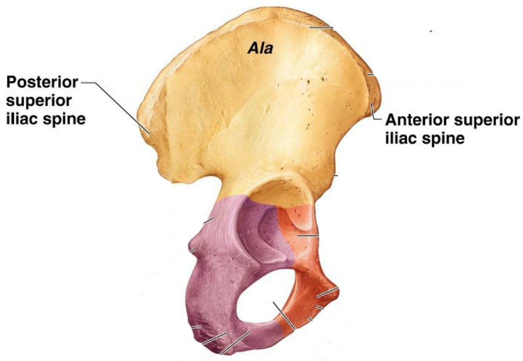


Figure 6: Diagram of the hip bone

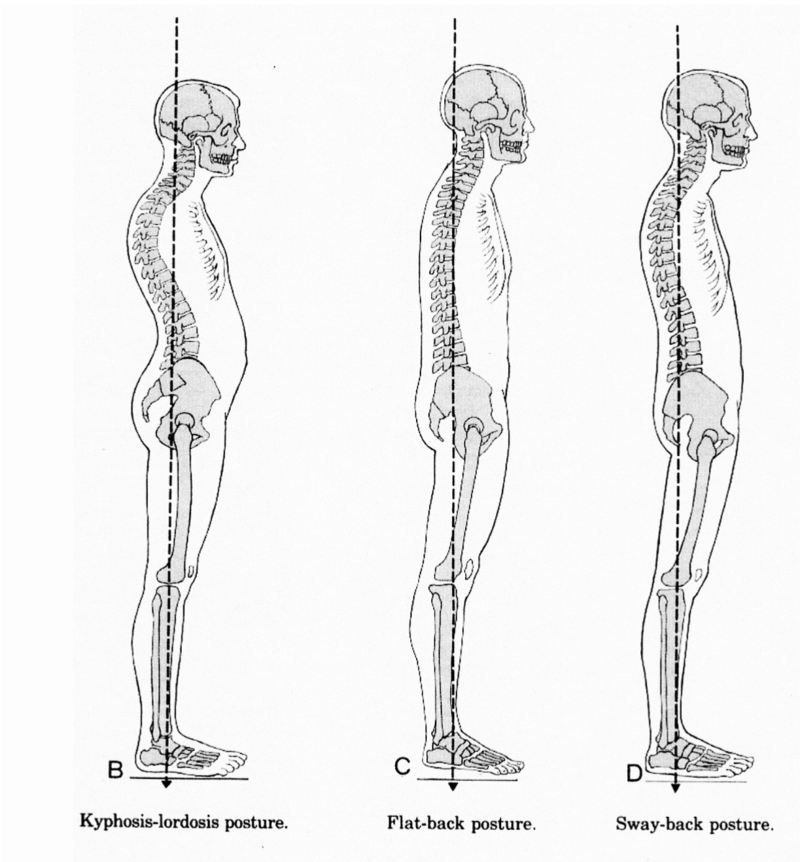


Figure 7: Four types of postural alignment

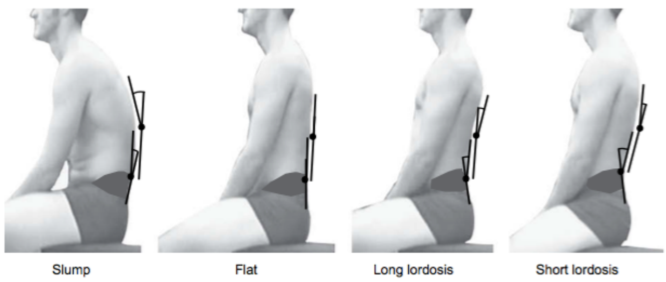


Figure 8: Non-ideal seated posture and three proposed ideal seated postures [36]

Claus et al [36] found that it was easier for their participants to get into the slump, flat and long lordosis postures, whereas manual assistance was needed to get into the short lordosis posture. The authors did not find specific physiological benefits of one of these porposed ideal postures over the others. A study which relied on the evaluation of 295 European physiotherapists found that the experts considered the long and short lordosis seated postures to be ideal [37].

CAUSES AND EFFECTS OF POOR POSTURE Poor posture is defined as any prolonged deviations from the "neutral spine" [18]. It is often caused by muscle imbalance, which means that certain muscles get tight or shorten while others lengthen and weaken. Today, posture issues are commonly related to unhealthy sedentary behaviour, especially in combination with computer usage. Sitting for extended periods of time causes tight hip flexors, which pulls the pelvis forward, causing Kyphosis-lordosis. Further, people tend to hunch over their keyboard and stretch the head towards the screen, which leads to tight chest muscles causing forward-head posture or rounded shoulders. Additionally, sitting in a prolonged deviation from the neutral spine flexes the lower back, which pressures the lumbar spines, causing muscle cramps, nerve blocking and decreased blood flow. This, in turn, can lead to lower back pain and leg pain. Thus, there is evidence that addressing these postures may help reduce lower back pain [37].

But there are many other causes for poor posture: Pain or past injuries can cause poor posture, as people tend to overcome pain by changing their body position, which can become a habit. Being overweight can facilitate poor posture, as the added weight changes the body's center of gravity. Genetic predisposition, low nutritional state, lack of awareness of correct posture, poor core stability / fitness and even wearing high heels are further potential reasons one may develop poor posture.

Moreover, poor posture has long been linked to several psychological issues, negative emotions, feelings of stress and lack of motivation [5]. These can be both causes and effects of poor posture. Participants experimentally positioned in a slumped-over, relative to upright, physical posture showed significantly lower persistence on a standard learned helplessness task and rated themselves higher on stress levels [4]. They were also perceived as more depressed and helpless by others. Patients presenting depressive episodes showed a marked increase in kyphosis, which was also reduced during remission. Kyphosis affects the muscles, reducing the flexibility of anterior thorax (intercostal) muscles, upper limb muscles originating from the thorax (minor and major pectoralis, latissimus dorsi and anterior serratus muscles) and cervical spine muscles (levator scapulae and trapezius muscles) [3].

POSTURE CLASSIFICATION Classical posture classification and evaluation methods are based on visual reference points. This type of evaluation, called manual posture assessment by means of observation, is performed either on the basis of a physiotherapists expertise or by calculating the angles between bone reference points. Typically, the subject is positioned in front of a checkered background.

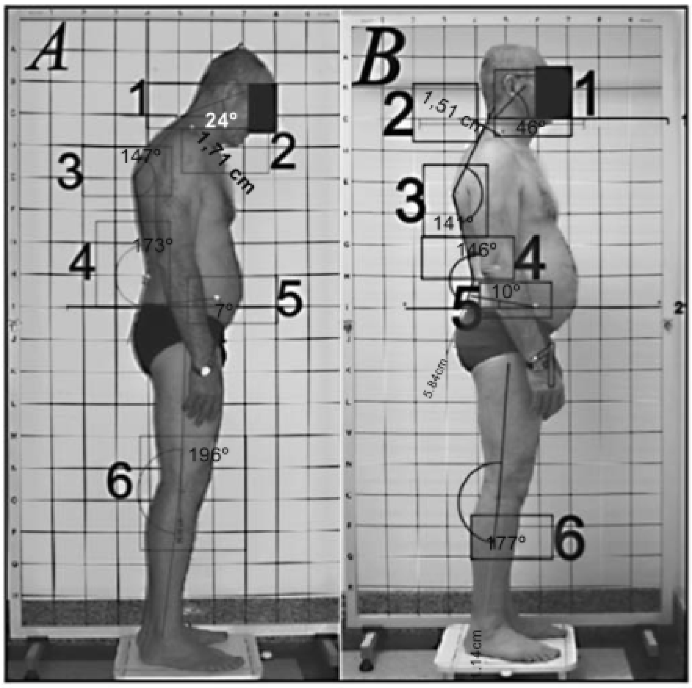


Figure 9: Visual Reference for Posture Evaluation. Showing a person with a depressive episode and during remission. [3]

In some cases, the reference points are marked with adhesive dots or small balls [3]. Points typically investigated are: lateral malleoli; head of the fibula; greater trochanter of the femur; anterior and posterior superior iliac spine; cervical spine (at C7); thoracic spine (at T3, T6, T9 and T12); lumbar spine (at L3 and L5); sacral spinous processes; and inferior scapular angle. Some of these reference points were also marked with small balls (15 cm in diameter): anterior and posterior superior iliac spine; thoracic spine (at T3, T6, T9 and T12), lumbar spine (at L3 and L5); cervical spine (at C7); and acromion. This can be seen in Figure 9.

A study has shown that the accuracy of manual assessment has an average probability of misclassification of 30.1%, compared to measurements from an optical motion capture system [38]. Further, this method provides only a momentary 'snapshot' impression, and is not suitable for continuous observation and real-time feedback. It is also possible that people correct their posture towards a more socially acceptable version rather than posing naturally. There are video camera- and Kinect-based automated systems for posture classification, which have shown to be more accurate than observation by professionals [39], [18]. Most relevant for this project, there has been substantial work on using wearable devices for posture classification. These are described in Section 2.3.

FLEXPOINT HYPOTHESIS The flexpoint hypothesis was inspired by the 'Posture Theory Diagram', as shown in Figure 10. On this diagram, it can be seen that the front of the body compresses during slouching. We call the point on which this happens the 'Flexpoint' of a person. The hypothesis consists of three parts, which are addressed in this thesis:

1. Every person has a flexpoint when slouching.

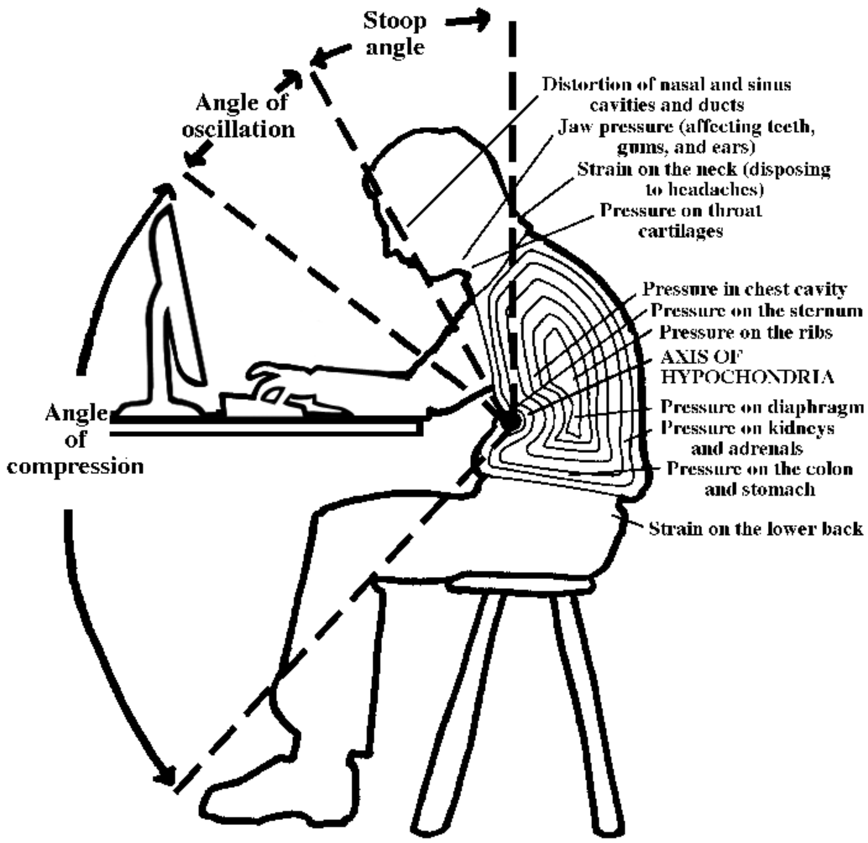


Figure 10: Posture Theory Diagram

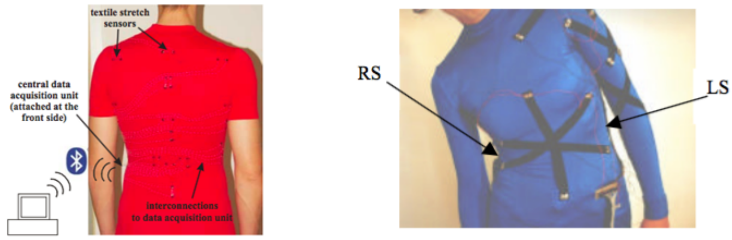
2. The position of the flexpoint can be measured.
3. Slouching can be detected by measuring the amount of bending at the flexpoint.

2.3 STATE OF THE ART

2.3.1 Wearable coaching

The topic of wearable coaching is relatively new. Asselin et al [40] implemented a wearable computing platform consisting of an array of sensors and application software to motivate users to reach fitness goals and prevent harm in a real-time environment. The system consists of an accelerometer and a heart rate monitor, which enable detection of the performed exercise and exertion. Custom software uses the data to provide interactive audio feedback for motivation, prevent harm and warn user of overexertion, logging of exercise data. It also uses exercise history to optimise progress.

The system was tested with 65 users for timeliness and accuracy of the feedback, as well as non-intrusiveness and wearability. The authors concluded that the system was overall perceived positively, but most benefits those who exercise infrequently. They found a relation between the intrusiveness of the system and intention of future use, indicating that only a system that



(a) [41] (b) [42]

Figure 11: Prior work using strain sensors

is not perceived as intrusive will be adopted. While not directly targeted at coaching posture, we consider the insights gained in this study to be relevant for all types of wearable coaching systems, including for this thesis.

2.3.2 Wearable posture assessment

The common thread across systems is to detect an undesired behavior that is known to increase the risk developing musculoskeletal symptoms and to provide a user intervention to attempt to change behavior [39]. A long-term field analysis of seated posture thus requires that the user be fitted with a simple, easy-to- use, wearable posture monitor that requires neither alteration of the work environment nor the use of a computationally complex data processor [6]. Existing research falls into three categories: elongation sensors, bend sensors, and inertial sensors.

STRAIN AND ELONGATION SENSORS Mattmann et al [41] examined the use of textile strain sensors directly integrated into a tight-fitting garment to detect upper body positions. In a study with eigth participants posing in 27 different postures, they found this approach to be feasible at a detection rate of 65% for a new user and up to 97% accuracy with a user-specific setting. Similarly, De Rossi et al [42] measured trunk posture with a sensorised leotard that incorporates a multitude of strategically placed elongation sensors. Their work, however, has not been evaluated formally, as it is intended only as a proof of concept to demonstrate the feasibility of creating smart garments capable of monitoring human posture. Both works can be seen in Figure 11.

FLEX AND BEND SENSORS Dunne et al [6] measured seated posture using flex sensors along the spine. They found that measuring bend across the area of the spine between the C7 and L4 vertebrae provides the best indication of goodness of posture across a varied subject population. They further compared four different flex and bend sensors: a polypyrrole-coated open-cell foam sensor, two piezo-resistive sensors, and a plastic optical fiber sensor. These can be seen in Figure 12. While only the foam sensor was excluded for lack of accuracy, the authors used the optical fiber sensor as this was available in a format long enough to cover the aforementioned spinal area.

INTERTIAL SENSORS Inertial sensing and accelerometer-based motion capture is the most common form of wearable monitoring of body position and

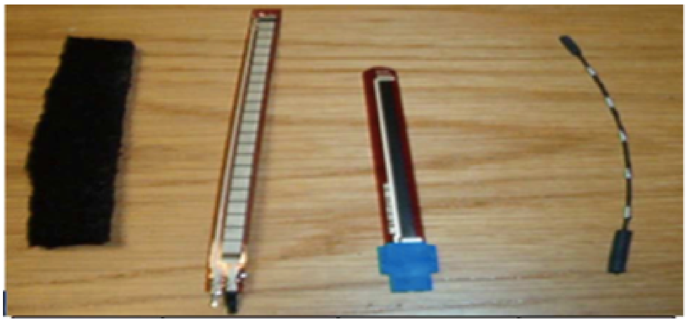
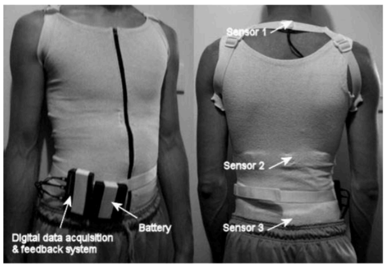


Figure 12: Bend Sensors investigated in [6]

(a) [7]



(b) [18]

Figure 13: Prior work using IMUs

movement [6]. As accelerometers are only capable of measuring acceleration, they are less well-suited to detecting position or slow movements, and they are often used in conjunction with orientation sensors such as gyroscopes. There are self-contained systems that combine these sensors, called inertial measurement units (IMUs), that are frequently utilised, e.g. in the recent work of Wang et al. [7] and Wong et al [18]. Both approached use multiple IMUs integrated into garments, located on the back of the wearer to measure spinal curvature. They can be seen in Figure 13.

2.3.3 Real-time feedback on posture

There are few studies that evaluate the effect instant feedback can have on posture. To our knowledge, the first one has been conducted in 1970 by O'Brien and Azrin [43]. They administered feedback in form of a mild vibrotactile stimulus to the shoulder when participants slouched. They found that all participants slouched less when stimulation was provided. In their conclusion, they highlight the impact of motivation for posture correction to the success of the intervention.

O'Sullivan et al [44] evaluated real-time haptic feedback on posture in form of vibrations. With their wearable system, a participant receives vibratory biofeedback from the BodyGuardTM device to change their sitting posture, if slouching beyond an individualised threshold of proper posture is recorded. The authors were able to show significantly reduced lower back pain within a single session, however long term effects were not part of this study.

(a) LumoLift **(b)** iPosture **(c)** Prana

Figure 14: Clip shaped posture trainer devices

Wong et al [18] developed an IMU-based smart garment, which detects changes in posture with regards to curvature variation of the spine to facilitate posture training. The garment provides acoustic feedback in form of five short repetitions of a tone from a buzzer. In total, this feedback lasts approximately two seconds. Their results showed that the device could reduce time spent in prolonged poor postures of the spine by 40%.

2.3.4 Commercially available products

There are several commercially available wearable devices for posture improvements. All of them are built on the premise outlined in the previous section, that real-time feedback can help users to improve their posture. The LumoLift, iPosture, and Prana devices are quite similar: they all take shape as a clip that can be attached to the wearer's everyday clothing. They measure posture using IMUs and provide haptic feedback using vibration motors. They can be seen in Figure 14.

Upright is a device in form of a small silicone stick that is attached to the wearer's lower back using adhesive tabs. It combines an IMU with a specially-designed strain sensor to detect slouching. Upright too utilises vibration feedback. LumoLift, Prana and Upright additionally include a Bluetooth module, which allows pairing with the respective mobile application. Further, there is the Spidermed II, which also utilises an IMU, but provides audible feedback when poor posture is detected. These two devices can be seen in Figure 15.

The commercial success and positive review of these devices serve as an additional indicator that real-time feedback can work as a tool for posture improvement. Where available, we looked at product reviews and found that users reported posture improvement and relief of related discomforts, increased awareness and a better understanding of what constitutes correct posture. Criticism varied per device, but can be summarised as complaints about accuracy in posture detection and issues with usability - unclear interaction, lack of instructions - or durability.

(a) Upright (b) Spidermed II

Figure 15: Alternative posture trainers

3 IDEATION

3.1 EXPERT INTERVIEWS

During ideation, a series of unstructured interviews with experts have been conducted. Especially in the early stages of this phase it appeared more important to let them speak, rather than following a prepared set of questions. This approach allowed to find out which aspects they empathised, and also to learn about new aspects that might not have come up else. The interviews served as introduction to understanding posture and as basis for initial brainstorming. As a general conclusion, the interviews highlighted the potential and novelty of the flexpoint approach, and provided valuable background knowledge to start outlining the project.

3.1.1 Kristin

Of essential importance were first interviews with Kristin, who introduced the initial idea and the flexpoint hypothesis as introduced in Section 2.2. Prior to the interviews, Kristin, who has a background in physical therapies, had already rapidly tested the idea using off-the-shelf flex sensors. She found that a flex sensor, attached to the sternum, could provide an indication of a persons posture in the sense of standing or sitting up tall. She further found that the sensor needs to be tightly attached to the body, which is not intuitive at that location. We replicated and extended some of her results in a rapid prototyping session.

3.1.2 Physiotherapists - Matthias and Rik

To be able to address the issue of poor posture it was important to gather background knowledge on posture. Questions like “What is correct and incorrect posture?”, “Which types of incorrect posture exist?” and “How can people learn to adjust themselves to a correct posture?” required input from experts on the field. Further, the general possibility of measuring posture on the front of the body. Two physiotherapists, Matthias Hilgers and Rik Schurink, were consulted on these questions.

Matthias, who was consulted first, provided detailed instructions on how to achieve ’ideal’ posture. He particularly emphasised on positioning of the feet and distributing body weight evenly. He also explained four different common types of incorrect posture that were treated in Section 2.2: sway back, lumbar lordosis, thoracic kyphosis and forward head.

The interview with Rik focused on seated posture, but also covered his take on the flexpoint hypothesis. He explained that the ideal seated posture is a very personal issue that varies from person to person, which explains the lack of consensus found in literature. He considered the flexpoint hypothesis as relevant and a reasonable approach. He pointed out that it has not

Figure 16: Interaction Suit Posture Sensors

been considered by physiotherapists because they cannot treat the front of the body. He further emphasised the necessity to test whether a flexpoint measurement would also be suitable to detect misplacement of the shoulders, as this is one of the most common issues of people that sit too much and work with computers.

3.1.3 Bart

Bart Klaassen is pursuing a PhD at the Biomedical Signals and Systems research chair at the University of Twente. His expertise are in motion capture, fitness and rehabilitation, currently he is developing a wearable system for monitoring stroke patients in the home environment [45]. In an initial meeting, we discussed aspects of posture, existing technologies that are used to measure posture as well as areas of application for the product. The main issue of existing posture measurement devices, as the one that can be seen in Figure 16, he identified was the price and thus availability to users. Application areas he envisioned were the sports and particularly bodybuilding sector, but also rehabilitation for e.g. stroke patients.

3.2 CREATIVE IDEAS (FLASHES OF INSPIRATION)

In the early ideation phase, a large amount of ideas were generated. These were not necessarily limited to the flexpoint hypothesis, but also diverged into other means of measuring posture using smart garments. While the main purpose of this idea generation was inspiration, we found that several approaches were worth reporting. These could potentially be used to augment and enrich a flexpoint-based posture garment.

3.2.1 Posture socks / shoe soles

This idea, rooted in the interview with Matthias, is based on the concept that good posture begins with correct foot placement. This concept, which is also commonly promoted in yoga, assumes that one can stand correctly if the body weight is evenly distributed over the feet. This means equal

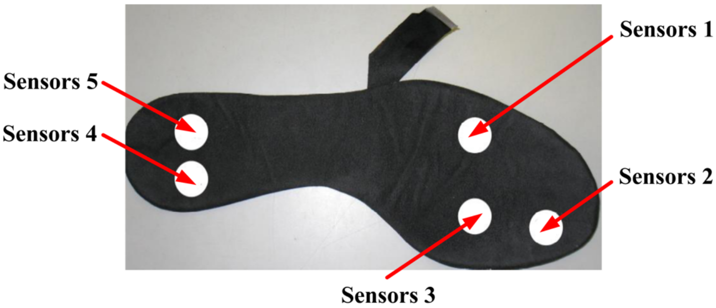


Figure 17: Pressure sensitive shoe sole

pressure on both feet, but also over the individual foot. The heel, balls of the foot and big toe should evenly press into the ground. This could be measured by distributing pressure sensors on a shoe sole or the sole of a sock. The readings from these sensors should then be equalised by distributing the body weight evenly. For hygiene and wearability aspects, the socks idea was discarded quickly. The shoe sole idea however seems appropriate, as it turned out these already exist for medical and research purposes, as depicted in Figure 17.

3.2.2 Posture panties

The concept of posture panties is rooted in yoga, where one learns that to sit correctly, both sitting bones should be placed on the ground. Again, pressure is to be spread equally on both sides. In a similar fashion to the shoe soles concept, pressure sensors below the sitting bones could be utilised to measure. The idea was developed in discussion with Kristin and Angelika, and hinted in interviews with the physiotherapists, who both said that correct positioning and the ability to move the sitting bones are essential for healthy sitting.

The idea was rapidly tested with Bart, who has access to the above mentioned pressure sensitive soles. For testing, we placed two Xsens MTw CE prototypes under the sitting bones, which utilise a custom Zigbee based protocol to wirelessly stream sensor values to a computer in real time. This setup, which can be seen in Figure 18, was tested on potential sitting surfaces of differing structure. In particular we tested on the hard ground, a soft couch and an intermediate office chair. On each ground, several correct and incorrect postures were formed.

As a result of this testing, measuring posture in this manner was possible only in a limited way. On the hard surface, sensor readings were accurate and clear, whereas the softer surfaces swallowed the effect, and readings were not conclusive. Further, the setup detected only whether one was balanced on the sides, but not whether one was e.g. slouching.

3.2.3 Mechanical posture correction

Typically, methods for posture correction function in a rather mechanical way: they use firm materials to pull the wearers shoulders backwards and thus force better posture. This idea, which was explored in a paper proto-

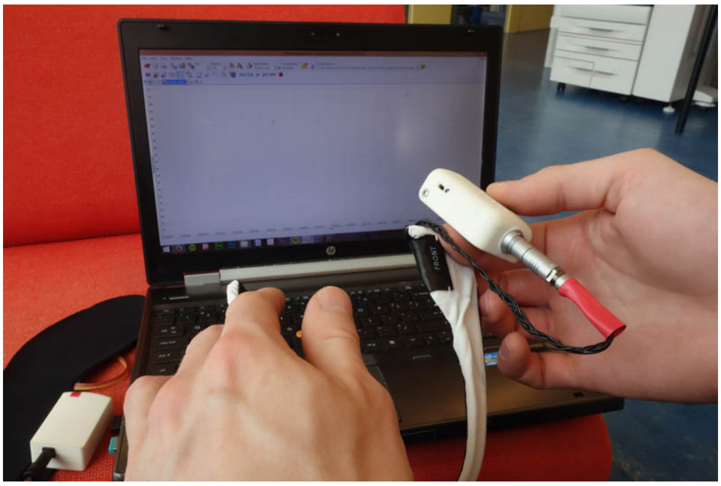


Figure 18: Setup to rapidly test posture measurement by sitting bone pressure

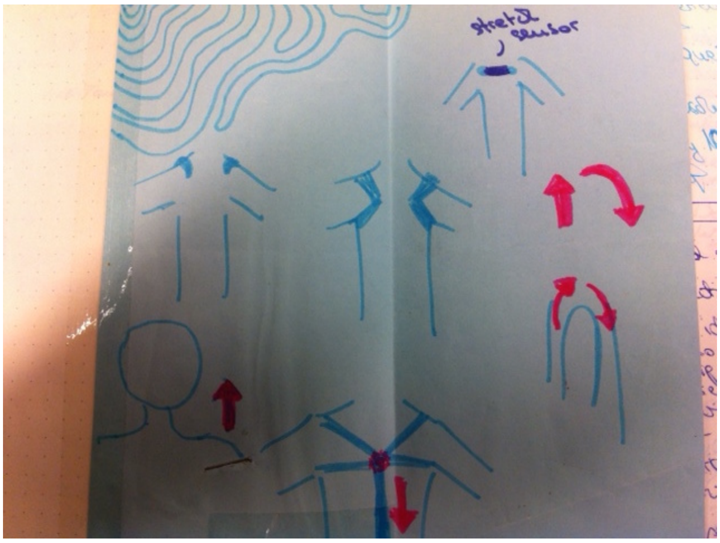


Figure 19: Concept sketches for the Mechanical posture correction idea

type, takes this to a new extreme. A stretch sensor attached to the front shoulders measures whether it is being stretched to a certain degree, indicating correct posture / shoulder position. If this is not the case, a motor is activated that pulls loops around the shoulders back and down. The concept is illustrated in Figure 19.

3.2.4 Necklace and earring set for forward-head detection

Many of the initial ideas focused on correcting Thoracic Kyphosis or rounded shoulders. However, forward-head posture is equally common amongst the target group. In a correct posture, the ears are located straight above the shoulders, whereas with forward-head, as the name suggests, the ears are located in front of the shoulders. By measuring the angle between ears and shoulders, this incorrect posture could thus be detected. For this purpose, a hall sensor, is attached to the wearers shoulders / neck in form of a necklace. It is accompanied by a matching set of earrings with integrated magnets. The distance between the sensor and the magnet determines the wearers posture.

3.3 RAPID PROTOTYPING SESSION

The initial exchange with Kristin led to a rapid prototyping session to gain understanding of the explorations she already made and potentially gain further insights. In this session, we first recreated her experiment by simply holding a piezoresistive flex sensor to the sternum. After posing in various forms of poor posture, the issue of attachment to the body was addressed.

To suit the female body shape, the sensor was embedded into a cone-shaped piece of fabric, which was then attached to an elastic underbust belt. Wearing this construct confirmed the difficulty of attaching the sensor firmly on the sternum location. Two thin elastic bands reaching from the top of the cone around the neck were used to correct this. This design however was found to be inappropriate for comfort as well as aesthetic reasons.

As an alternative method of sensing posture, using a stretch sensor to measure distance between the shoulder blades was tested. We found it to be capable of detecting poor shoulder position. However, it seemed that this type of sensor might miss certain forms of poor posture. It was concluded that it might be useful to use a stretch sensor in the shoulder area to augment measuring at the flexpoint using a flex sensor.

Finally, the topic of appropriate and desirable feedback was addressed. All options as presented in Section 2.1.2 were discussed. Vibration seemed most appropriate given its low level of obtrusiveness. For rapid testing, vibrating electronic toothbrushes were used. By holding a toothbrush to different points along the spine, several potential locations for feedback were identified.

3.4 CONCLUSION: STATEMENT OF THE PRODUCT IDEA

Based on the insights drawn from the context and ideation phase, the product idea is formulated as:
"A garment which measures posture based on the flexpoint hypothesis and provides real-time feedback to the wearer for wellness applications."
The reasoning of this idea, which already includes certain design decisions, is described in the following paragraphs:

A GARMENT As discussed in Chapter 2, a wearable device or smart garment is suitable for posture monitoring as it is location independent and allows for continuous observation and feedback.

WHICH MEASURES POSTURE BASED ON THE FLEXPOINT HYPOTHESIS As discussed in Chapter 2, posture has a profound impact on both physiological and psychological well-being. Given that poor posture is an increasingly ubiquitous issue, the development of an intervention is necessary.The flexpoint hypothesis is the novel aspect of the design, and provides a clear distinction from prior work as reported in Chapter 2. A rapid prototyping session has confirmed the potential of the hypothesis. This work sets out to further investigate the existence of the flexpoint and its location.

AND PROVIDES REAL-TIME FEEDBACK TO THE WEARER Real-time feedback on posture can improve overall posture and reduce posture related discomforts, as explained in Chapter 2. By learning how correct posture feels, muscle memory can be trained so that it becomes more natural to sustain a correct posture over time. Which output modalities are most appropriate for the given product is one of the questions investigated in this work.

FOR WELLNESS APPLICATIONS As pointed out in Chapter 2, the wellness sector is particularly interesting for the development of such a product. Not only has posture influence on several aspects of general wellness, but the sector also aims at prevention of discomforts, such as the ones that could be caused by ongoing poor posture. A wellness application also entails that the product should be comfortable and that feedback should serve as a 'gentle reminder', rather than a punishment for negative behaviour.

These requirements are further extended in the following chapter, towards clear specifications.

4 SPECIFICATION

4.1 USE CASE SCENARIO

To derive further specifications beyond the product idea specified in Section 3.4, the following use case scenario was envisioned:

1. office scenario, person sitting in front of computer
2. the person slouches
3. slouching detected by the garment
4. immediate feedback
5. posture correction

4.2 FLEXPOINT STUDY

This section described a study that was performed to answer Posture Question 1d "Does the flexpoint hypothesis hold?". As stated in Section 3.4, the flexpoint hypothesis showed potential during the initial rapid prototyping session. However, before designing a product around the idea, it was necessary to gain deeper insights into the flexpoint. Therefore, a survey with 50 participants was performed.

OBJECTIVES There were two objectives to this survey:

1. Confirm that every human flexes at some point between sternum and navel when slouching
2. Find out relation between location of that point and body shape / abdomen circumference

Two hypotheses were formulated in this respect:

1. Everybody flexes at some point between sternum and navel
2. There is a relation between body shape and location of the flexpoint

DESIGN Survey and measurements. Participants are asked to measure the distance between sternum and navel, sternum and flexpoint as well as their belly at the point of the largest abdomen circumference. Further they are asked to identify with a body shape by looking at Figure 20. The main outcome measures are the mean and median flexpoint location, and a possible relation relation between the body shape / abdomen cirdumference and flexpoint location.

PARTICIPANTS Males and females above 18 years old. In total, 50 people participated in this study, 16 female and 34 male. All participants were recruited at the University of Twente, they were either students or employees. All body shapes were represented at least once.

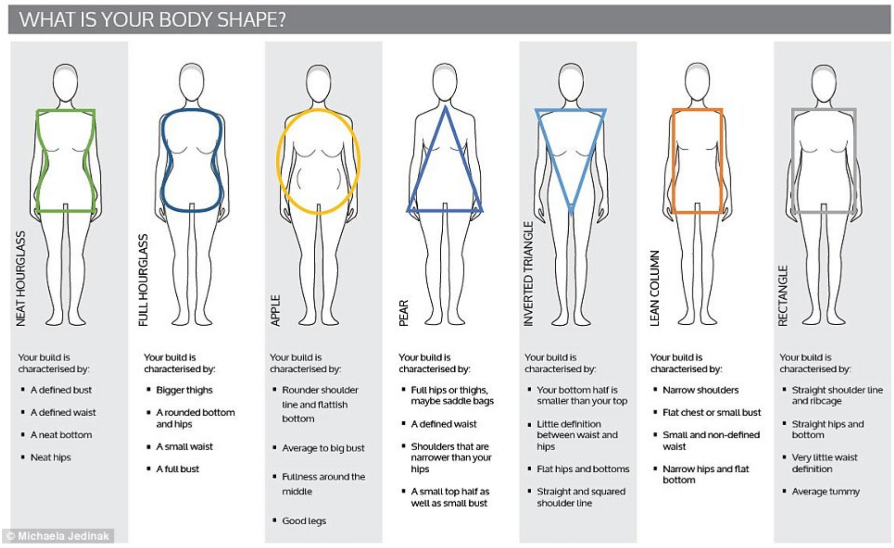


Figure 20: Bodyshapes with descriptions, as presented to the participants

RESULTS It was possible to measure a flexpoint at every participant. The distance between the lower end of the breast bone/sternum and the navel of participants ranged from 10 cm to 25 cm, with a mean of 16.7 cm (standard deviation 2.86), and a median of 17 cm. The flexpoint location ranged from 0 cm - right at the lower end of the sternum - to 15 cm. The mean flexpoint location was 6.45 cm (standard deviation 5.31), and the median 7.75 cm.

Simple linear regression analysis showed that there is no significant supported relationship between the flexpoint location and abdomen circumference ($F = 3.533$, $p = 0.066$), neither between flexpoint location and bodyshape ($F = 0.833$, $p = 0.551$).

INSIGHTS / SPECIFICATIONS DERIVED FROM THIS The existence of the flexpoint can be considered confirmed. However, the location varies between individuals, without a visible pattern. A garment that measures posture at the flexpoint should take this into account. Two possible approaches are envisioned at this point: either the sensor spans all possible flexpoint locations, i.e. has a length of at least 15 centimeters, or the location of the sensor is adjustable to the individual wearer.

4.3 SENSOR SELECTION

After showing the existence of the flexpoint in the previous section, we set out to answer Posture Question 1e, “Which type of technology can be used to measure posture at the flexpoint?”. Since the flexpoint describes a bending in the front of the body, sensors that can measure bend or flex were the intuitive choice. As prior work described in Section 2.3, we began with commercially available piezoresistive flex sensors, which are available in 5.6 cm and 11.4 length respectively. While they function very reliably, this restriction in length made it impossible to account for all possible flexpoints as defined in the previous section. They are however suitable for designs with adjustable sensor location. As an additional consideration, these sensors are

Figure 21: Considered Sensors, from left to right: custom Velostat / conductive mesh bend sensor, Velostat / tape bend sensor, stretchy conductive fabric stretch sensor, conductive jersey stretch sensor, piezoresistive flex sensor

comparatively expensive.

We further experimented with several custom bend sensor designs based on Velostat or pressure sensitive fabric. Four different versions were produced, three of them using Velostat, and one using the fabric. They all function in the same manner: the pressure sensitive material is layered between two layers of a more sturdy material. When this material is bend, the inner layer gets pressured at that spot, thus producing a change in material resistance as a result. We tried out a mesh, sticky tape and neoprene as sturdy material variations. The main advantage of these custom builds is the flexibility in length and width. The sensors did measure bending, but lacked accuracy and consistency in values over time, which made them inappropriate for usage in this project, despite high wearability, especially of the fabric version.

We also explored the option of reverse strain sensors, such as that a strain indicated correct posture and absence of strain a poor one. However, this approach was found not to be suitable, as the sensors, pieces of various conductive stretch fabrics, would wear out from being stretched continuously. Further, the constant pull led to displacement of the garment itself. All options explored are shown in Figure 21.

Finally, we explored the option to measure an angle using a Hall Effect Sensor and a magnet attached on a hinge. As long as the magnet is fixed on a constant distance to the sensor, this approach brings reliable and consistent sensor readings. It was advanced further in wearability by using a neoprene based hinge, which can be seen in Figure 22. In conclusion, this and the piezoresistive flex sensor were found to detect bending at the flexpoint most reliable.

4.4 FEEDBACK STUDIES

Two micro-studies were performed to answer Design subquestion 2(b)i "Which type of Feedback is appropriate?". These are described here.

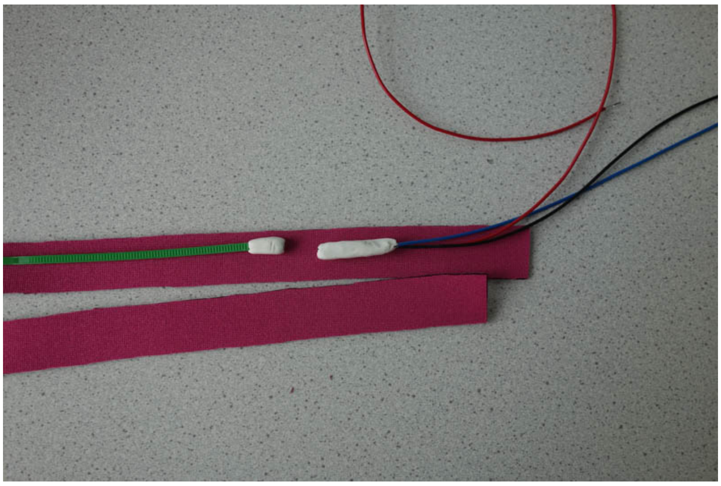


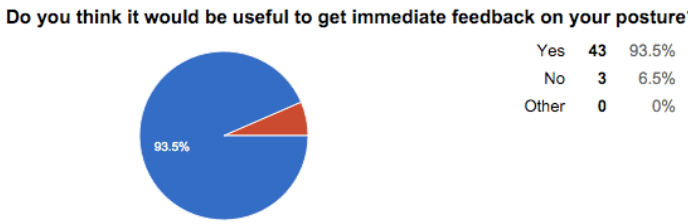
Figure 22: Hall Effect Sensor Neoprene Hinge

PREFERRED FEEDBACK STUDY In context of the flexpoint study, 50 users were asked for their preferred form of feedback on poor posture. With the objective to find out user preferences for immediate feedback. The topic was addressed in two simple questionnaire items: "Do you think it would be useful to receive immediate feedback on poor posture?" and "Which type of feedback do you find suitable?". Options offered include vibration, sound, light, temperature, feedback on a screen and 'other'.

The results are summarised in Figure 23. With regards to usefulness, 43 participants answered that they would find immediate feedback useful, three stated that they do not. Another four participants decided not to answer this question. Nevertheless, all 50 participants decided to provide information on a preferred feedback modalities. It was possible to make multiple selections. Suggestions for 'other' included 'Picture that changes', 'on smart watch', 'sound, but only with headphones', 'poking', 'Periodic reminder', 'data visualisation' and 'olfactory', each being suggested once. As can be seen, vibration feedback was most popular and will thus be utilised further in the design process.

VIBRATION POSITIONING STUDY This user test determines optimal positioning of vibration motors for feedback on poor posture. We aim to find the most effective and pleasant position for vibration motors on the wearer's back. In this within-subject experiment, different positions of vibration motors on the participants back are compared. The positions, which can be seen in Figure 24 have been informed by acupressure points and interview with physiotherapist.

Two partial prototypes that allow priming with vibration were prepared for this micro-study. One of them took shape of a simple butterfly patch to be positioned along the spine, the other a 'V' shape that could be laid around the participants shoulders. These extensions to the vibration motor were made from felt and developed to spread the vibration over a larger surface, as we found priming with only the motor too isolated and intense. Both can be seen in Figure **??**. The functionality was limited to turning the vibration motor on and off. The patches were held against the participant's back at different positions, and the motor turned on for three seconds. After each



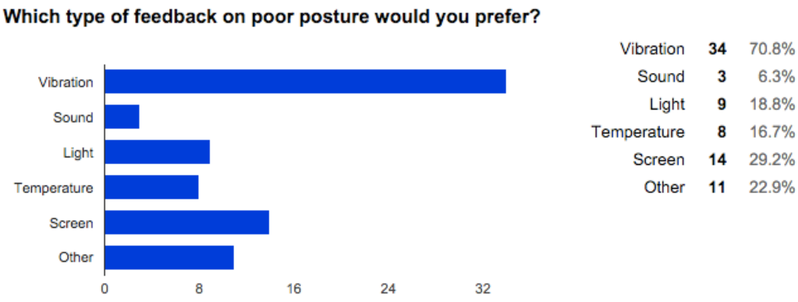


Figure 23: Results of the preferred feedback study

position, a short questionnaire was issued. The items in this questionnaire, each to be rated on a 5-point-scale, are:

1. How much did you notice this feedback?
2. How pleasant was this feedback?
3. How strongly does this feedback motivate you to correct your posture?

Three participants took part in the test. There was not much variance in intensity and pleasantness within participants. Mid-back and shoulder locations were rather unpopular. Two participants agreed upon a position between the shoulder blades to be most motivational to correct their posture, whereas one named the low back position as most motivational. Given this result, these two positions were further investigated in the following prototype iterations.

4.5 ITERATIVE DEVELOPMENT OF PROTOTYPES

In this section, an iterative design process is utilised to answer Design Question 2b "What is a desirable user experience for this project?". A series of prototypes has been developed and tested, with focus on subquestions 2(b)i "Which type of Feedback is appropriate?" and 2(b)ii "Which form factor is appropriate?". Each iteration is described in terms of hardware, software and form factor, and concluded by the insights drawn from that iteration. The iterations have been developed in close cooperation with Angelika.

4.5.1 First iteration: The crop top

The very first prototype was developed on basis of the insights gathered in the rapid prototyping session, described in Chapter 3. It takes shape of a custom crop to design, which was developed to incorporate two sensors: a

Figure 24: Potential positions for vibration feedback

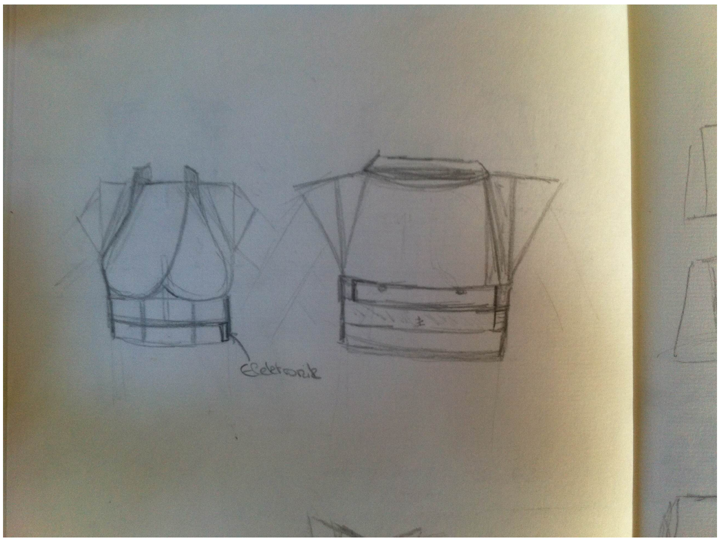


Figure 25: Sketches for first iteration

Figure 26: First iteration

piezoresistive flex sensor to measure the flexpoint, and an additonal stretch sensor to measure shoulder positioning, in particular whether or not the user would draw her shoulders forward. One of the key design challenges from the beginning was how to securely attach the flex sensor tightly to the body. In this design, we decided to utilise the fact that female users would wear a bra underneath the shirt. The midsection of the bra is used to keep the sensor in place. To achieve this, the sensor was fitted into a small pocket attached to the inside of the shirt. It is attached only on one side, held to the body by a tight underbust belt. The other side can be slipped below the bra. Since this is a little tricky to do, it was decided that the shirt could be opened in the front.

To integrate the shoulder stretch sensor, a loop around the shoulders was designed, consisting of the sensor and elastic band, resulting in a halterneck design, as can be seen in Figures 25 and 26. An ATtiny85 microcontroller is used to read both sensors and to drive a vibration motor. The circuit board further includes a button, which is used to trigger calibration mode. It is attached to the shirt using Velcro, and hidden behind a flap. In this way, the electronics can be removed for washing or maintenance. The stretch sensor, which is integrated into the garment, is connected to the board using little connectors. This version uses a very simple code, which consists of calibrating the sensors if the button is pressed, establishing a threshold value based on the calibration and letting the motor vibrate as long as the threshold is passed. The electronics are powered via USB using a battery bank usually used to charge phones on the go. As the shirt itself does not have space for the battery, it is carried in the wearer's pants pocket.

INSIGHTS / SPECIFICATIONS DERIVED FROM THIS ITERATION The prototype was worn by one of the researchers for two hours each on two consecutive days. This initial wearing already provided several insights with regards to user experience. The prototype was found to successfully detect slouching, however the sensitivity of the threshold was perceived as too low. Further, the sensor tended to move out of the pocket after a while, which was unpleasant to the wearer as the plastic of the sensor directly touched her skin. Further, the adjustments to put it back in place were perceived as socially awkward. On a similar note, the connectors for the stretch sensor tended to slip away, leaving the sensor disconnected. This however led to the insight that it could be considered superfluous, as the prototype still detected slouching reliable. On further experimentation, it turned out that it is nearly impossible to slouch ones shoulders forward while keeping the flexpoint straight.

It was also found that the immediate feedback was perceived as annoying, as the prototype would vibrate in situations such as opening a door, or reaching for something at the end of the desk. This highlighted early that a shirt with such functionality should be of low intrusiveness. False negatives are preferable to false positives in such an application. Another insight derived from this iteration concerns sensor calibration: having a button to trigger calibration was perceived as burdensome, and the lack of feedback on being in calibration or not was confusing to the wearer, especially because the button could have been pressed by accident. Finally, it was found that the halterneck crop top design did not allow for accurate positioning of the motor, and the motor touching the wearer's skin directly was inconvenient.

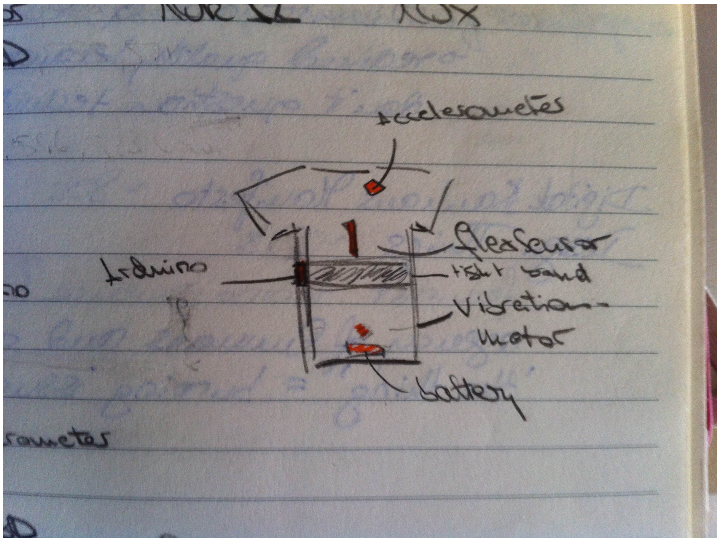


Figure 27: Sketches for second iteration, V1

4.5.2 Second iteration: The T-Shirt

The second iteration covers a series of prototypes, which are incremental improvement to one another. Each addressed some of the issues identified during the first iteration, and new issues identified from the second iteration. They are outlined one by one in this section.

Iteration 2.0

The most pressing issue identified was the irritating feedback in inappropriate moments. To address this, an accelerometer was added to this iteration. As a consequence, the microcontroller had to be exchanged, as more pins were needed. An Arduino Nano is used instead of the ATtiny. The software was adjusted to distinguish between three use cases: sitting, walking and short time poor posture. The premise is that if movement is detected by the accelerometer, the poor posture is likely to be short term, thus no feedback is given.

To address the issues with calibration, the button was removed, and the software was adjusted such that always the first ten seconds after turning on the device were used for calibraiton. A RGB LED was added to indicate that the device is in calibration mode. A more traditional garment cut was utilised to allow positioning of the motor at the lower back. This also had the advantage that the motor would not touch the wearer's skin directly.

INSIGHTS / SPECIFICATIONS DERIVED FROM THIS ITERATION This iteration was worn by another researcher for several days, for differing time spans. Wearing the prototype for more than two hours at once revealed that wearing the battery in pants pocket was a hassle underestimated before: the wearer would frequently forget about the battery when visiting the restroom, pulling down their pants and thus disconnecting the device and putting strain on the USB cable. Further, without the custom underbust belt, the sensor did not stay in place properly. We aimed to address these issues by attaching an elastic band to the outside of the shirt, but it was not a truly

Figure 28: Iteration 2.0

convincing solution, as the band tended to move and not hold the sensor properly.

Iteration 2.1

The following iteration contained the same software and hardware configuration, but had a bustier sewn in, which would keep the sensor in place. The battery bank was attached directly to the shirt, on the side of the body at ribcage height. This spot was estimated to be least intrusive. While it indeed did not hinder body movement comfort, the battery bank was perceived as bulky and heavy. As a purely cosmetic improvement, the accelerometer was hidden behind a fabric flower.

INSIGHTS / SPECIFICATIONS DERIVED FROM THIS ITERATION The main insight from this iteration was that more research into appropriate power sources was needed. While the battery bank is convenient because of the USB connection and users already being used to it, the form factor was perceived as a major drawback. Trying to find a version that is flat and

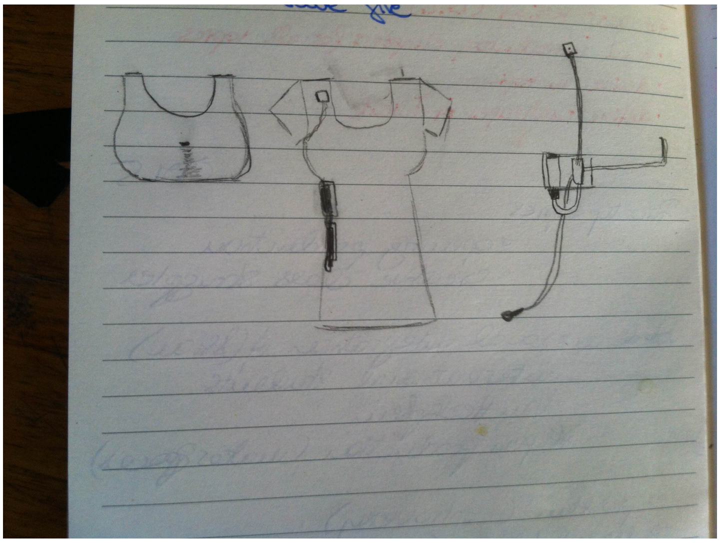


Figure 29: Sketches for Iteration 2.1

lighter was not fruitful. Further, the added value of the accelerometer was questioned. At least with the software used in this iteration, it was debated whether the functionality could not equally well be achieved with implementing a delay, as suggested by [39]: "Whenever the subjects posture moves into a bad state for more than a threshold period of time, the intervention triggers". Further, wearing the prototype and discussing it with other brought up social considerations. There are many reasons why a wearer would want to improve their posture, and it might be uncomfortable to make this goal public by wearing the posture improvement garment publicly. Further, there is the aesthetic and fashion-related concern of wearing the same shirt many days in a row.

4.5.3 Third Iteration: The bodysuit

The third iteration aimed to address issues of sensor location and fit, as well as wearability of the design. Based on the insights gather from the second iteration, it seemed necessary to take a step back and simplify. Further, it was decided that for the aforementioned social and aesthetics considerations, the new iteration should fall into the category of undergarments. It should further be sleeveless, to reduce risk of sweating. A new form factor, a bodysuit, was utilised to make sure the sensor would stay in its intended location and not move with body movements. Further, this iteration used a custom bend sensor made from Velostat and neoprene. As explained earlier, this custom design allowed measuring across all possible flexpoints, at a length of 18cm. The sensor was attached to the inside of the garment, so its stretchy material would keep it close to the body. We removed the accelerometer from this design, and instead implemented a feedback delay, which allowed switching back to the ATtiny microcontroller. Another new aspect that was explored in this iteration was the implementation of a soft circuit. We used Arduino Lilipad components and replaced most wires with conductive thread. Only the motor stayed connected with traditional wiring. We placed Velcro at the back of the garment and the motor to allow adjustment to different motor positions. Further, this iteration was powered by just a 2032 cell coin battery.

Figure 30: Iteration 2.1

Figure 31: Sketches for third iteration

INSIGHTS / SPECIFICATIONS DERIVED FROM THIS ITERATION Unfortunately, the first insights gathered from this iteration were learned before ever wearing it: the soft circuit turned out to be inadequate. Practical issues such as knots loosening, but also electronic problems caused by the high resistance of the thread rendered the soft circuit version unusable. Therefore, we exchanged all carefully stitched connections and soldered wires in their place. Afterwards, the prototype was worn for four non-consecutive days. The wearability of this iteration was considered high, especially due to the small and lightweight components, and the sensor attachment to the body was appropriate. Further, the delayed feedback made the prototype less intrusive and annoying. However, attiring a bodysuit felt awkward as compared to the T-Shirt form factor of the previous iteration. Further, the sensor seemed of questionable reliability. The cell coin battery, while pleasant to wear, lasted only one day of wearing.

4.5.4 Fourth Iteration: The shapewear

Like in the second iteration, the fourth iteration covers several incremental prototypes.

Iteration 4.0

The experience with the third iteration highlighted that a tight, bodyfitting garment is necessary to measure posture at the flexpoint reliable. For the fourth iteration, we therefore utilised foundation garments (so-called shapewear) as basis for the design. This type of underwear intends to make the wearer's body appear more slim, and is thus very close-fitting. Given the questionable reliability of the Velostat based sensor, we investigated other, more durable options to detect poor posture at the flexpoint. In this iter-

Figure 32: Third iteration

Figure 33: Iteration 4.0

ation, we used the neoprene based Hall-Effect sensor / magnet hinge, as described earlier. We further integrated a felt piece along the spine, which allowed to spread the vibration feedback over a large area. The circuit board was minimized to a size of 2.5cm x 3cm, and attached in the collarbone region. For power, we returned to the initial battery bank, which is a compromise on wearability, but more economically and ecologically responsible than exchanging non-rechargeable batteries every day.

INSIGHTS / SPECIFICATIONS DERIVED FROM THIS ITERATION This iteration was worn by a researcher for six non-consecutive days. It was perceived as pleasant to wear and performed its functionality reliably. One point of criticism was the thermophysiological comfort: the large felt patch made the back of the shirt extremely warm and caused sweating. Apart from this, this iteration was considered feasible enough to be tested with participants other than the researchers.

Iteration 4.1

This iteration, again based on a store-bought foundation garment, was identical to iteration 4.0, apart from replacement of the large felt patch with a smaller butterfly patch to increase thermophysiological comfort. It was worn by two individuals, for three consecutive days each. Due to the lack of stability caused by removing the large patch, attiring the close-fitting shirt was considered more difficult. Therefore, a zip fastener was integrated on the side of the shirt.

INSIGHTS / SPECIFICATIONS DERIVED FROM THIS ITERATION This iteration was worn by a participant in context of the pilot study, as described in Chapter 6, for three consecutive days. While the butterfly patch was perceived as positive, the zip fastener was found to make attiring the prototype even more tedious. Rather than improving the user experience, it made it more frustrating, because it was difficult to pull both sides tight enough together to close the zip fastener, and then one would still need to pull down the fastener itself. It was decided to omit this feature in future iterations. Further, it was decided to add data-logging features, so that the prototype itself would collect data on the wearer's posture. The participant also found that continuous feedback during poor posture was highly intrusive. Since this was also a significant energy drainage, we decided to alter the feedback to two short 'buzzes', that would be repeated after a while if the posture was not corrected. In addition, the option to 'snooze' haptic feedback for a limited amount of time should be added. Apart from these last changes, the fourth iteration was considered successful, and served as basis for the development of final product specifications.

4.6 CONCLUSION: FINAL SPECIFICATIONS

In this section, we draw conclusions based on the insights gathered in this chapter. This results in the final specifications, thus answering Design Question 2c by making design decisions explicit. The final product specification is formulated as: "A close-fitting undergarment for women which measures seated posture based on the flexpoint and provides haptic feedback on prolonged poor posture." As with the initial product idea, we break this specification down to explain and elaborate design decisions.

A CLOSE-FITTING As the series of prototypes revealed, a tight fit of the garment is essential to posture detection based on the flexpoint. The sensor must be closely attached to the body to deliver reliable results.

UNDERGARMENT The product should be worn discreetly under the wearer's everyday attire, for two reasons: in order not to restrict the wearer's regular wardrobe, and not to make the aim of improving posture obvious to others. Especially if the motivation for posture improvement is psychological, the wearer might not want to draw attention to it. Further, the undergarment should be sleeveless to allow variety in outer garments and for thermophysiological comfort.

FOR WOMEN The user group for this project has been limited to female users. Tests with male users revealed that sensor positioning is more problematic for males, especially because they tend to be uncomfortable with close-fitting garments.

which measures seated posture at the flexpoint Seated posture has a significant influence on standing posture. Given that most people spend more time sitting than standing, and seated posture has clearly been linked to multiple discomforts, a focus on seated posture aims to solve the problem at its root. As the flexpoint hypothesis has been confirmed and prototypes have successfully measured poor posture at the flexpoint, the final product should logically continue this approach. The device must therefore detect slouching based on bending of the front body. For this to work with a variety of wearers, it must allow calibration to suit the individual.

and provides haptic feedback Our preferred feedback study has clearly indicated that haptic feedback using vibration motors is seen as most desirable for a product with the envisioned functionality. It is discrete, and can serve as a 'gentle reminder', rather than a punishment for negative behaviour. Feedback should be given between the shoulder blades or at the lower back. It should be administered in a unobtrusive manner, in particular in short signals rather than continuous vibration. There must also be an option to turn haptic feedback off for a limited amount of time, for situations in which the wearer is not able or willing to keep a correct posture.

on prolonged poor posture If feedback is given too quickly, this can be annoying and intrusive to the wearer. The garment should therefore not react immediately on detection of poor posture, but delay feedback until prolonged poor posture is established.

5 REALISATION

The final specifications, as described in the previous chapter, served as a basis to implement four prototypes to be used in evaluation. This chapter describes the realisation of these final prototypes in detail, with regards to hardware, software and the garment itself.

5.1 HARDWARE

We started with realising the hardware for the prototypes. Given the evaluation-specific specifications to include data-logging, new hardware components has to be introduced in addition to the established vibration motor, Hall-Effect sensor / magnet neoprene hinge and LED. In particular, we decided to add a TinyRTC Real Time Clock for recording the time, and a Sparkfun microSD Breakout board to write the data on. This required more pins and computing power, as well as support of the SPI and I2C communication protocols, so the ATtiny was replaced by an Arduino Pro Mini. This microcontroller supports all needed functionality and measures only 1.8 cm x 4.2 cm.

To assemble the boards, we had assistance from an electrical engineer, who checked the circuit and provided many practical insights on how to improve durability of the design. Under his guidance, the electronic boards were densely designed and equipped with strain relief measures. The first finished board can be seen in Figure 34.

5.2 SOFTWARE

We completely restructured the code for the final version, to incorporate data-logging and the new feedback pattern. The full code can be found in Appendix A. A finite state machine was chosen, since it provides clarity and structure to the code and allows clear distinction of use cases. The final software allows for the following functionality:

CALIBRATION OF SENSOR READINGS For the first ten seconds after turning on the system, sensor values are read. The smallest and largest detected readings are saved, and updated should a smaller or, respectively, larger value be registered. In the meantime, the LED is turned on to indicate calibration to the wearer.

DETERMINATION OF APPROPRIATE THRESHOLD VALUE Based on the calibration values, an appropriate threshold value, which indicates poor posture, is chosen. From interviews with a physiotherapist and confirmed in self-tests, we learned that for seated posture this threshold lies at one third, seen from the 'best posture'. Once this threshold is established, the software switches into the 'good posture' state.

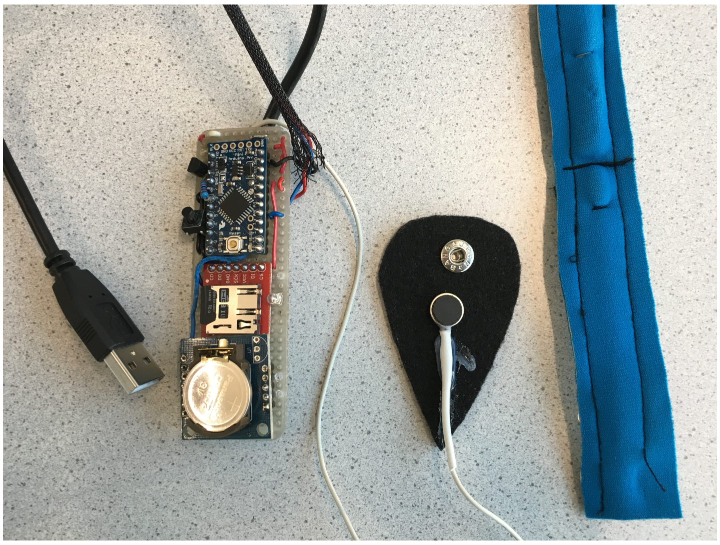


Figure 34: Circuit board

DETECTION OF POOR POSTURE BASED ON THRESHOLD VALUE In the 'good posture' state, sensor values are checked twice every second. As long as the values do not pass the threshold value, the software stays in this state. Once the threshold is passed, the software switches into an intermediate state. During this state, which accounts for the delay of feedback, sensor values are read more frequently. If a value below the threshold is read, the software switches back into the 'good posture' state, assuming that it was only a short deformation of the posture, to e.g. reach for something or close ones shoes.

GIVE DELAYED FEEDBACK If, however, all values stay above the threshold, thus indicating continuous poor posture for 15 seconds, the software switches to the 'poor posture' state and haptic feedback is triggered. The vibration motor is turned on for one second, turned off for one second and then turned on for one second again. This pattern mirrors the short 'buzzes' of a phone receiving a text message. If the wearer corrects her posture, the software switches back into 'good posture' state, else the haptic feedback is repeated after ten seconds.

SNOOZE HAPTIC FEEDBACK We identified several use cases during which a wearer might not want to receive feedback on their posture for a limited time, such as during a commute or in times of high focus, when posture does not have the highest priority. For such cases, a snooze function was implemented, which turns off the feedback for one hour on the press of a designated button. If the wearer wishes to receive feedback again before the end of the hour, she can simply press the button again.

DATA-LOGGING The software records when the 'poor posture' state is entered, and when it is exited. It additionally writes down the calibration and threshold values, as well as the value that triggered the 'poor posture' state. Each such record is written as a new line in a comma separated spreadsheet on the microSD card.

Figure 35: Butterfly Patch to distribute vibrations

5.3 TEXTILE

For the garment itself, sleeveless black shapewear shirts acquired at Primark were used as a basis. They were selected based on their tight fit and stretchy fabric properties. Each was equipped with fabric cable tunnels, as well as a butterfly patch made from felt, as seen in Figure 35. This patch holds the vibration motor and distributes the vibration over its surface. Each shirt was further equipped with a strip of Velcro to attach the sensor. Further, a small custom shoulder bag was sewn to carry the board and battery bank. An example of the resulting prototypes can be seen in Figure 36.

(a) Front

(b) Back

Figure 36: Resulting prototype

6 EVALUATION

"If a device doesnt help someone change their behavior, how long will they keep using it? It needs to make a difference to be valuable over the long term." - Aaron Filner (Facebook)

This chapter sets out to answer Evaluation Questions 3a "How to design a user study that evaluates effects on posture?" and 3b "Does the design have the intended effect on the wearer's posture?".

Most prior work concentrated their evaluation on technical functionality of the respective sensor for posture detection, but did not evaluate the actual effect on posture of participants ([6], [41], [7]). Few researchers have tested the combination of sensing posture and providing real time feedback and investigated its effect on posture. Wong et al [18] had five participants use their smart garment in 4-day trials for 2 hours continuously a day during their leisure time at home. The garment itself was used for data collection, and evaluation took place based on time spent in correct posture compared to poor posture. Another study investigated the effect of real-time spinal postural biofeedback with 24 participants while watching a DVD for two hours.

While these studies show positive indications of the effect of real time feedback on posture, we believe that to be able to make a statement about the actual effects of the developed technology on posture, it has to be tested over a time span that allows behavioural changes and in a real world scenario. Therefore, prototypes are handed out to participants to wear 'in the wild', thus in their everyday life. The prototype as described in Chapter 5 is handed out to participants over the time span of three weeks, during which they are asked to wear it as often as possible during their work week. Ideally, this should result in fifteen days of wearing the prototype. This time span was chosen as a compromise between the time it takes to change a habit, begin to build muscle memory and feasibility within the scope of this thesis. Their posture before and after is compared based on self-evaluation as well as evaluation by a physiotherapist.

There are two main research questions to this study, centering about the effect and user experience of the design:

1. Does posture improve when wearing the prototype frequently?
   a) Is the improvement subjective, objective or both?
   b) Does an improvement in posture relate to an improvement in perceived well-being?
   c) Is the envisioned usage - 15 days, as long as wanted per day- appropriate to achieve effects on posture?
2. How is the user experience of the prototype perceived?
   a) Is the prototype easy to use?

b) Is the prototype pleasant to use?

c) How can the user experience be improved?

6.1 METHOD

6.1.1 Research Design

The study comprises of a within subjects comparison of perceived and observed seated posture before and after wearing the developed prototype for three weeks. The mixed methods evaluation is based on qualitative self-assessment of posture (subjective improvement) collected in individual semi-structured interviews, quantitative trend in the data logged by the prototype and qualitative expert judgement by a physiotherapist by means of video analysis (objective improvement). With this mixed approach we aim to ensure in-depth insights into the effectiveness of the developed concept and prototype. To investigate influence on well-being, a daily questionnaire is administered. Addressing the second research question, qualitative data on the user experience during the study is collected during the closing interview.

6.1.2 Pilot

A shorter pilot study was performed to ensure the envisioned methodology is appropriate and the research instruments, in particular the interview protocols, are valid and complete. To gain high quality insights, a researcher was recruited to participate. She was informed beforehand that she would be treated as any other participant, except for the reduced time span of the experiment. However, she could provide feedback or questions on the methodology at any point. The pilot revealed several issues with regard to setting, procedure and ethical considerations which have been addressed before begin of the study. In particular, this resulted in a change of location for the interviews, adjustments in the procedure, additional consultation with the ethics commission and inclusion of additional questions during the interviews, as well as baseline days, where the prototype only measures, but does not provide feedback to the participants.

6.1.3 Participants

The evaluation study featured four participants, aged between 23 and 24 years. All of them were female graduate students at the University of Twente. They were recruited based on their outspoken interest of improving their posture and the requirement that they spend at least eight hours a day sitting. Their sedentary behaviour ranged from sitting 8 to 14 hours a day. They differed in the amounts of breaks they take from sitting, from six times a day to two times per hour. All of them experience posture related issues, most commonly shoulder pain, which was mentioned by all four participants, followed by neck pain, back pain and feeling tired, which was experience by two participants each. Two participants added that they experienced psychological issues related to poor posture, feeling that it influences their self-esteem and impression on others.

6.1.4 Materials

INTAKE INTERVIEW QUESTIONS The intake interview aims to get to know the participants and their background. It therefore cover questions about their demographics, sedentary behaviour and motivation for posture improvement, in particular posture related issues the participants experience. These questions are based on the expert interviews with physiotherapists as well as the literature covered in Chapter 2.2. The full list of interview questions can be found in Appendix E.

DAILY QUESTIONNAIRE The daily questionnaire consists of questions about the participants wearing behaviour, in particular whether the prototype was worn that day, and if it was switched off. It further includes a short mood scale [46], which serves as a representative for wellness and well-being on the given day. Mood is measured on the dimensions valence, energetic arousal and calmness on two seven-point scales per dimension. The questionnaire, which is administered via automated email, also provides the participant with options to leave further remarks and to get in touch with the researcher the coming day. The full list of questionnaire items can be seen in Appendix D.

CLOSING INTERVIEW QUESTIONS Questions in the closing interview center around perceived posture improvement (usefulness of the device), usage behaviour, ease of use and intention of future use. These questions are loosely based on the Technology Acceptance Questionnaire [21]. Following the pilot, they were extended by questions about changes in posture awareness and how long the participant believed the effect of the prototype to last. The full list of questions used in the closing interview can be found in Appendix E.

EXPERT EVALUATION OF SECRET VIDEO RECORDINGS For an objective observation of improvement in posture before and after the intervention, we rely on the evaluation of an expert. For this purpose, the participants seated posture is filmed during both the intake and closing interview. In order to avoid impaired observations due to adjustment of posture because of the presence of a camera, these recordings are taken without knowledge of the participants. After the closing interviews, the recordings are shown to a physiotherapist for evaluation. For each participant, the videos are shown in a random order, the expert is then asked to make a statement as to which of the recordings shows a better posture overall.

DATA COLLECTED FROM SHIRTS The prototype itself records every time the participant receives feedback for poor posture. In detail, we record time of feedback, sensor value that triggered the feedback, minimum and maximum values of the calibration, and time of posture correction. With this data, we aim to make statements about the frequency of poor posture - occurence of poor posture per hour of wearing - and the response time to correct it. During the first and the last day of the study, the prototype is programmed to record as described, but without providing feedback to the user. These days serve as baseline observations for objective posture improvement, on the premise that less recordings of poor posture indicate an improvement in posture.

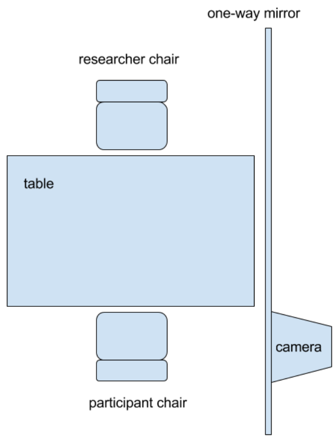


Figure 37: Setup for Intake and Closing Interviews

6.1.5 Ethical considerations

During the pilot, the question of bringing up the secret video recordings in the consent form was raised. In cooperation with the ethical committee of the faculty, it was decided that the first consent form brings up that audio or video may be recorded. Also, all video recordings are to be anonymised by blurring the participants face and removing the sound. After signing the consent form, the participants are slightly deceived by placing an audio recorder on the table during the interviews. After the closing interview, participants are debriefed on the secret recordings. They have the option to look at their anonymised video of the intake interview and to sign a second consent form, which explicitly asks for usage of the recorded video data. Both consent forms can be found in Appendix B. In addition to the consent forms, the preparation of an information brochure and manual for the prototype was resolved upon to ensure that participants would feel well-informed and cared for during the study, and that they would have a contact address besides the researcher in case of complications. These can be found in Appendix C.

6.2 PROCEDURE

Once the participant has shown interest in participating in the study, she is invited to an intake interview. This interview takes place in 'Empathise', a room in Designlab which is equipped with a one-way mirror. The room contains a table and chairs for the prospective participant and the researcher. A hidden camera is pointed at the participant's chair through the mirror. The setup can be seen in Figure 37.

The researcher greets the prospective participant and asks her to take a seat on the destined chair. She then briefs the participant with an outline of the study schedule, the experimental task and procedure, without mentioning the video recordings. The exact script can be found in Appendix F. If any questions arose, the researcher answers them at this point. The prospective participant is then asked to confirm her participation. After signing the consent form, the participant receives a printout of the interview questions to prepare. The researcher leaves the room and turns on the camera. To get a realistic view of the participants seated posture, without influence of the researchers presence, the participant is left alone for five minutes before the start of the interview. There are two aspects to this: participants may mirror the researchers posture, or adjust their own posture to make a better impression. On return of the researcher, the interview is held.

On another day following the interview, the prototype is demonstrated and handed over to the participant. The separation of interview and hand-over of the prototype was one of the findings of the pilot study, as conducting both combined was perceived as exhausting to the participant. First, the basic usage is explained and displayed. This consists of plugging in the battery, calibrating the sensor and testing whether the shirt reacts properly after calibration. The participant can do a dry trial before attiring the shirt if wished. She can then leave the room to change. She can practice to set up the prototype as she would in the morning. The participant is instructed to wear the prototype everyday, but to 'snooze' it on demand. Questions are answered if needed.

The participant can then take the prototype home. Ideally, she wears it below her regular work attire every day. The day following the hand-over is the first observation day, after that the prototype is usable in its full functionality. Every workday at 16.30h, the participant receives an automated email with the daily questionnaire. On Fridays, the researcher collects the prototype for washing and checking its functionality. The participant can schedule additional meetings or calls if there are any issues with the prototype or questions of any sort.

At the end of the study period, there is another observation day, followed by a closing interview. The setup is the same as for the intake interview. Again, the participant's sitting posture is secretly filmed. The interview centers around the perceived effects of wearing the prototype, and also crosses topics of user experience and technology acceptance. After the interview, the participant is thanked for their contribution. They are then debriefed about the secret video recordings, and asked to sign the second consent form.

6.3 RESULTS

6.3.1 Effect on posture

SUBJECTIVE IMPROVEMENT OF POSTURE The audio-recordings of the closing interviews were coded according to the topics perceived posture improvement, usage behaviour and ease of use. All participants reported that they experience a heightened awareness of their posture, even when not wearing the prototype. This is shown in Table 4. Two participants emphasised on their increased ability to recognise poor posture. As one of them stated: "I wanted to learn to notice myself when I'm not sitting straight - now it's almost like a Pawlow-effect". As a result, three of them correct their posture more frequently, these three also reported in the interview that they

Participant	Awareness before Intervention	Awareness after Intervention	Increased Awareness while not wearing Intervention
01	2 times / week	6 times / hour	yes
02	3 times / day	1 time / hour	yes
03	1 - 2 times / day	3 times / day	yes
04	2 times / day	3 - 4 times / day	yes

Table 4: Posture awareness

Participant	Occurrences of Poor Posture before Intervention	Occurrences of Poor Posture after Intervention	Days of wearing the prototype
01	2	2	12
02	6	3	10
03	10	4	14
04	6	4	10

Table 5: Observations and Days of Wearing

felt that the prototype enabled them to improve their posture and that their well-being had increased during the study. They reported reduced or even absent pain in their shoulders, back and neck. The fourth participant reported that she sometimes was aware of her poor posture, but did purposefully not correct it because it was too exhausting. She did not find that her well-being increased, but rather experienced back pain in the course of the study. Three participants reported that their posture awareness heightened to a level that they experienced 'phantom-vibrations' when they slouched without wearing the prototype. We further asked the participants whether they believe that the effect will 'stick', to which all of them replied that they assume their awareness will stay for a while, but is likely to 'wash off' after a few weeks. We asked them three weeks after the end of the study, and as predicted only one participant still felt the effect of wearing the prototype.

OBJECTIVE IMPROVEMENT OF POSTURE, DATA COLLECTED FROM SHIRT The data logged by the prototypes was extracted and divided into entries for every day. Duplicated lines were removed. First, the two observation days - the first and the last day of the study were compared. On both days, the participants wore the prototype for four hours. These can be found in Table 5. For three of the participants, the poor posture was detected less often after the intervention than beforehand. Because data for many days was missing it was decided that further analysis which was planned beforehand would not add much reliable information. It is also to be noted that all observations appear low compared to prior experience during the specification phase. Therefore, we emphasise on the results of the expert analysis.

OBJECTIVE IMPROVEMENT OF POSTURE, EXPERT ANALYSIS The secret video recordings during the intake and exit interviews were anonymised and shown to a physiotherapist for analysis of the participants' seated spinal posture. For each participant, the two videos were analysed individually, and a comparison was drawn. Stills of each video are shown in Figure 38. The stills of each participant were taken in corresponding activity on both videos to allow comparability. The expert observed improvements in seated posture for all four participants. For one participant, however, tended to compensate her improved lower back posture with a slight forward head while writing. He pointed out that the improvements are rather slight, and explained that this was to be expected given the comparatively short duration of the study. "Posture improvement takes more time than we want it to take, but the results are definitely steps in the right direction. It is especially important that people start recognising their own poor posture, so they can take actions to improve it. That's a strong empowerment and motivation, which is more important than the actual improvement of the spinal positioning in the beginning." Overall, he stated that the results of the study can be considered a 'big win', as they positively compare to the results physiotherapy could achieve given the time span.

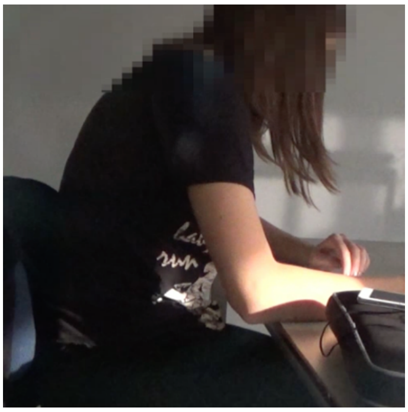
WELL-BEING As reported above, three of the participants reported in the closing interview that their well-being increased over the course of the study. The results of the mood items of the daily questionnaire, are shown in Figures 39 to 42. As can be seen on the plots, this data is also partially incomplete, as participants sometimes forgot to fill out the questionnaire. Two participants misunderstood the task and only answered the questionnaire on the days they wore the prototype, which makes it difficult to draw conclusions.

USAGE BEHAVIOUR During the closing interview, participants were asked about their actual and desired usage behaviour. All four participants stated that they would prefer to wear the prototype longer, as they expect an even stronger effect. Two agreed upon three to four weeks without interruptions as appropriate, one participant stated to wear it until the desired effect was reached and then stop. She added that she would probably not have the patience to wait for an effect for longer than six weeks. The fourth one estimated one to three months as necessary for significant improvements. It was further mentioned that a shorter duration per day would be sufficient in that case. Two participants experienced technical difficulties, which led to involuntary days of not wearing the prototype. Both of them found this to reduce the effect, they stressed the importance of continuous wearing.

The participants varied in how often they calibrated the shirt, from once a day to several times a day on demand. Calibration was not perceived as a difficulty. For two of them, wearing the shirt became part of their morning routine, and was perceived as a positive aspect of their day. As one of them states it, it felt like "having a guard that helps me today". The other two would sometimes forget to attire the prototype. All participants charged their prototypes every night. This was not seen as problematic, because it is a behaviour they already adopted for other devices, in particular their phones. The snooze button was overall not used often, as participants preferred to switch off the device entirely in situations where posture was not their highest priority or when it was perceived as annoying.

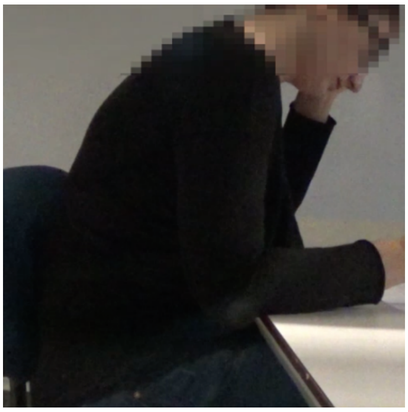
6.3.2 User Experience

APPLICATION AREA Three of the participants mentioned explicitly that the prototype worked well for correcting seated posture, but not as reliable for standing posture - at least not without recalibration. The fourth participant noted that the current sensor would not detect poor seated posture above a

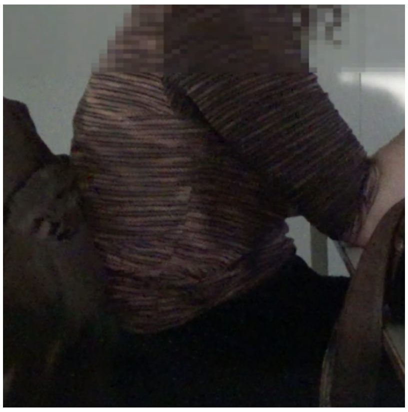


(a) Participant 1, before

(b) Participant 1, after



(c) Participant 2, before



(d) Participant 2, after

(e) Participant 3, before

(f) Participant 3, after

Figure 38: Before and after stills per participant

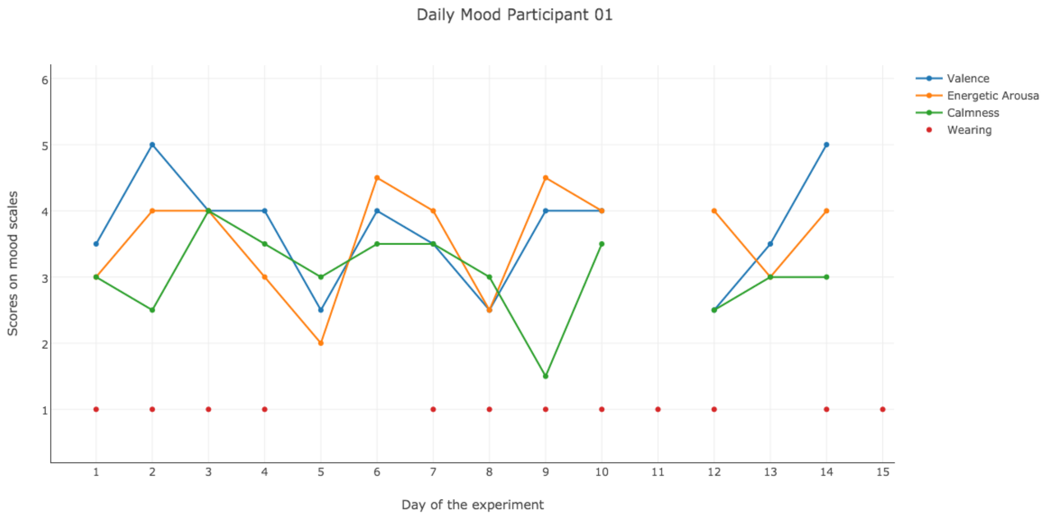


Figure 39: Mood results participant 01

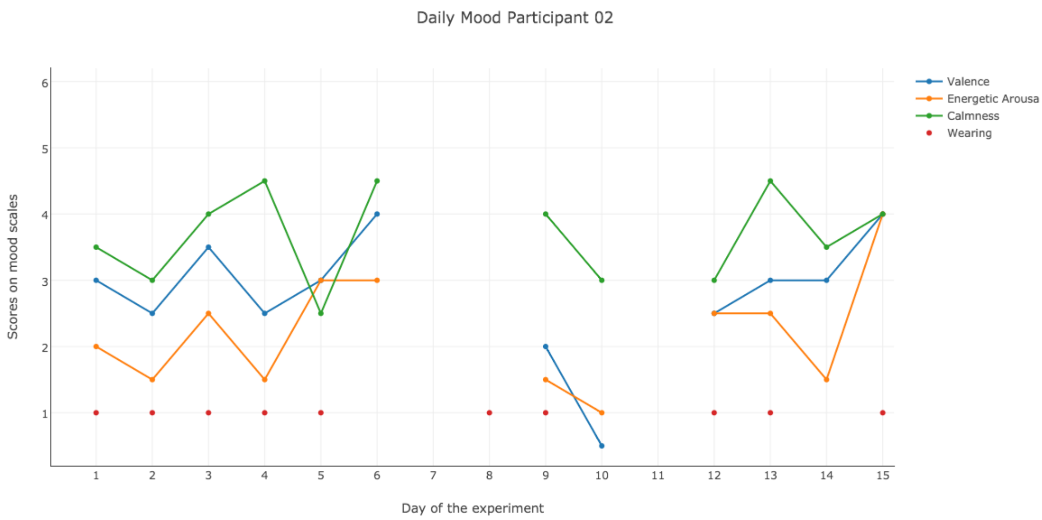


Figure 40: Mood results participant 02

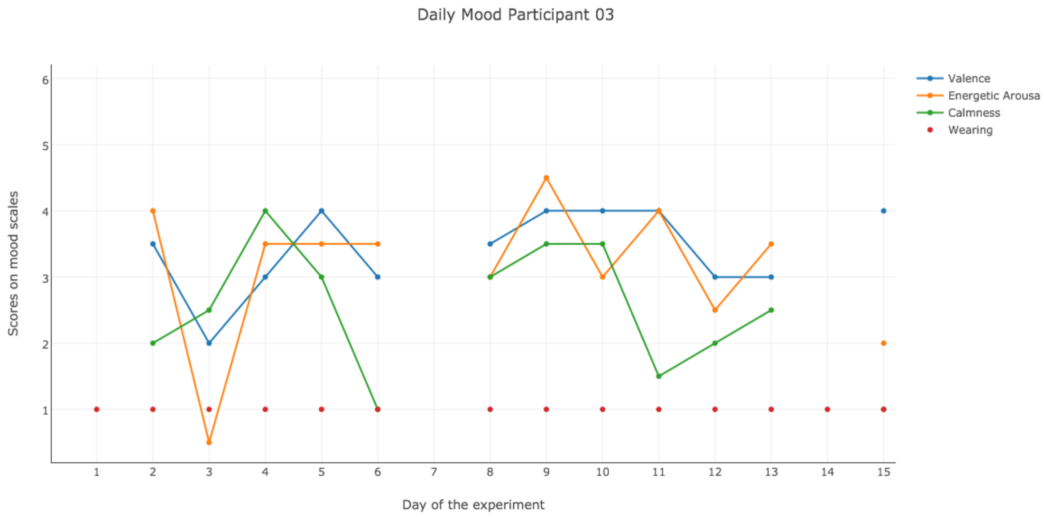


Figure 41: Mood results participant 03

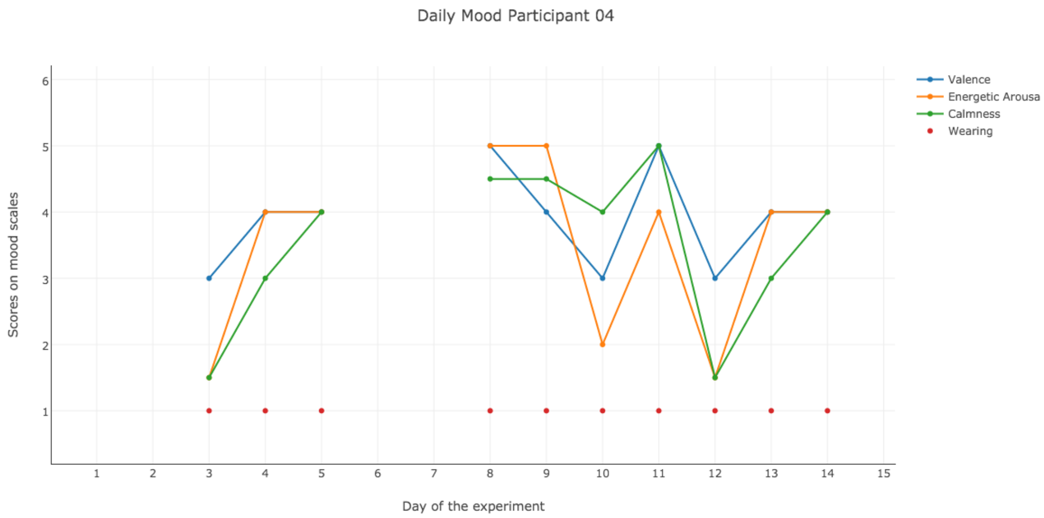


Figure 42: Mood results participant 04

certain threshold. This limits the application area to seated posture correction.

SOCIAL ASPECTS Three of the participants experienced reactions from their environment. This was mainly reasoned in the pouch which was part of the prototype, which would be visible. People commented on it, reacting curious to its purpose. One participant further reported that people would sometimes hear the vibration motor, checking their phones as a reaction to it. When sitting on a couch with others, they would even feel it. While the reactions were rather amused, these findings raise questions on how discrete the product can be.

USABILITY All four participants stated that they found the interaction with the prototype clear and understandable. Three added that they perceived the prototype as easy to use. "It was all very easy, there is nothing really you have to do with it..it's not complicated", to quote one of them. It was pointed out that visual feedback, in addition to the vibration, made interaction even easier, as it allowed to check one's posture before the haptic feedback threshold was passed. However, attiring the device was found to be difficult by all four participants.

COMFORT The user experience could further be improved in terms of thermophysiological comfort, as two participants pointed out that the prototype was really warm. While this was not a big issue at the point of this study (November - December), it might create discomfort and thus restrict wearability in the summer months. One participant reported that the tightness of the prototype would sometimes make her a little uncomfortable, especially after a big meal. She would feel relief when taking it off in the evening. Others found it not uncomfortable to wear.

DURABILITY The durability of the prototype was non-optimal. One participant reported that she was constantly worried to break the device. Two participants required repairs during the course of the study. This was mainly caused by the fact that the electronics were not integrated into the garment. Further, the custom sensor construct was not sturdy enough, leading to the sensor slipping out of the neoprene hinge and thus influencing the accuracy of values.

AESTHETICS AND FASHION When asked about aspects of aesthetics and fashion, participants stated that the garment design was pleasant, particularly because it was discrete. They agreed upon the desire for a neutral to sporty design, best in a black colour. Two participants made clear that they were rather indifferent towards aesthetic aspects in general, saying that the look would not matter much as long as it fulfills its purpose. One participant found the shirt to be too long. With the current prototype, the pouch containing the board was perceived as a hindrance in everyday life, as it interfered with wearing dresses or long shirts. With respect to aesthetics, future iterations should therefore aim to not disrupt the aesthetics of the clothing worn on top of it.

SUGGESTIONS Suggestions on how to improve the user experience that came up repeatedly were inclusion of a battery indicator and minimisation of the electronic parts in order to remove the shoulder bag. Further, participants suggested a closed box that could be attached outside of clothing to briefly check visual feedback, visualisation of (daily) performance and detection of activity, alongside with adjustments in sensitivity.

6.4 DISCUSSION AND CONCLUSION

6.4.1 Effect on posture

The subjective effect on posture can be considered positive: all participants reported increased awareness and most felt their posture related issues improved. There was also a consensus that the effect would be even stronger if the prototype was worn over a longer period of time. This was further confirmed in discussion with the physiotherapist.

When it comes to objective posture improvement, the expert evaluation confirms the subjective impression of posture improvement. The video analysis indicated a success in objective posture improvement. While the physiotherapist pointed out that the improvements were small in some cases, he was able to identify the before and after recordings for all four candidates correctly. He even saw an improvement in the participant who did not notice it herself. The data logged by the prototypes also indicates a positive trend. It is unfortunate that the data is incomplete, which also renders the existing findings from this source as questionable.

Overall it can be concluded that the prototype seems to be functioning well, but adjustments in usage behaviour are necessary to gain a stronger effect. In particular, this means wearing the device continuously for a longer period. The physiotherapist advised to develop a schedule which increases the duration of activity slowly, to avoid tiring participants and to optimise building up the muscles necessary to support a correct posture. He suggested to start with fifteen minutes during which feedback on posture is given, and increase by five minutes daily.

6.4.2 User Experience

The skin-tight garment is necessary to ensure the sensor is placed properly, but could impede user acceptance of a wearable device due to the social and physical comfort impact of wearing skin-tight clothing [6]. This was partially observed here, as attiring the device was perceived as difficult by all participants. Further, the prototype did not conform with durability requirements. It can be concluded that there are several points in which the user experience can be improved. The participants provided multiple useful ideas on how to do so, which will be considered in future work.

6.4.3 Study Design and Limitations

It is important to consider the limited generalisability of any result obtained with such a small sample size. Beyond that, the methodology chosen for this study might come with some limitations as well. Besides not being complete, the data collected by the prototypes could have been improved upon. Since calibration varies from day to day, simply counting the amount of feedback that occurred is a rather naive approach, and may not provide meaningful insights. In retrospect, at the least the observation days should have been measured based on the same calibration values to allow better comparability. Alternatively, a method of normalisation must be established.

As stated earlier, the duration of the study was a compromise. For future work, an extended time span would be desirable. Most participants of this study stated that they would have continued wearing the prototypes given a higher comfort and durability. Therefore, it can be expected that a longer study would be feasible. Ideally, weekly posture progress could be recorded, rather than just filming before and after.

Finally, it is open whether mood can truly be a reliable indicator of well-being. The results of the daily mood questionnaire do not clearly align with the participants statements about their well-being as collected during the closing interview. For future work, more research on adequate measurements for well-being is advisable.

7 DISCUSSION AND CONCLUSION

This work has used the creative technology design approach to address the overall question "*How can we design a wearable intervention for posture improvement based on the flexpoint hypothesis?*". We began with providing context on the topics posture and wearable devices to answer the questions 1a "What is the ideal human posture?", 1b What types of poor posture are there?, 1c "What is the state of the art in measuring posture?" and 2a "What are the factors that influence user experience of wearables?". In the ideation phase of the projects, these insights were deepened and shaped into a product idea by means of expert interviews and creative idea generation.

The rough product idea was then further specified. In practice, this was the most extensive part of the work, as we performed several formative user studies and designed and implemented an iterative series of functional prototypes. These were used to find answers to the questions 1d "Does the flexpoint hypothesis hold?", 1e "Which type of technology can be used to measure posture at the flexpoint?", 2(b)i "Which type of feedback is appropriate?" and 2(b)ii "Which form factor is appropriate?" At the end of the specifications phase, the final product idea was clearly described and provided the basis for realisation of hardware, software and garment, thus answering question 2c "What are the design decisions?".

It was found that the flexpoint hypothesis holds, and that it provides a novel and implementable approach to assess seated posture. It does however rely on tight-fitting garments to allow reliable sensor readings. For wearable smart textiles, a sensor position that is customized to the anthropometric measurements of the user is advocated [47]. This yields not only for sensors positioned at the trunk, but also for sensors positioned on the front of the body, as we have done in this work. Several sensors were considered appropriate for measurement at the flexpoint, but not all conformed with wearability requirements. We further learned that vibration feedback between the shoulder blades is an appropriate form of feedback, and that feedback should be given in moderation.

The resulting prototype was then realised and evaluated in terms of question 3b "Does the design have the intended effect on the wearer's posture?". It was found that the design clearly has a subjective effect, and an expert also confirmed an objective improvement in the participants posture. It is hypothesised - by us, the expert and as well as by the participants - that a longer duration of frequent wearing would result in an improvement that is objectively measurable.

During the evaluation, our knowledge about a desirable user experience was further extended, leading to suggestions for future design iterations. Next to the accuracy it is important to consider practical and even mundane aspects of garment design that influence directly the wearer's experience, e.g., material texture, tightness of fit, ease of putting on and taking off, as well as aesthetic aspects of clothing, etc [7]. The main issue that must be addressed in terms of user experience is the attiring process. Getting into the tight clothing was the most negative point mentioned by all participants. Further, additional control in form of added feedback should be provided.

Overall, the design can be considered to achieve Wearability Level 2, as defined by [32]: "System is wearable, but changes may be necessary, further investigation is needed".
In conclusion, this work set out to design a solution to improve the wearer's posture based on a novel approach. The developed design shows potential, but leaves room for further improvements. Further, this work contributed to the field by addressing the evaluation of effectiveness of posture related interventions with frequent usage, a topic that has not been addressed much in literature so far.
With regard to the process, we found that the creative technology design approach is generally suitable to design and develop wearables. One difficulty we found, compared to other technologies, was that aspects of form and function are more deeply entangled. This makes it harder to develop partial prototypes that test only one aspect. As described in Chapter 4, changing the garment design often necessitates a change in technology as well.

7.1 FUTURE WORK

7.1.1 Product

Based on the insights gained in this thesis, there are several aspects of the wearable user experience as outlined in Chapter 2 which have turned out to still be problematic, or which have not been addressed in the scope of this project at all. These are outlined here.

APPLICATION AREA While we are satisfied with improving seated posture to increase wellness for our users, there has been a major limitation in the work. So far, the prototype has been mainly developed for female users. This was primarily due to the tight form factor, which was perceived as uncomfortable by male users, as well as anatomical differences that made sensor positioning easier on females. However, males are likely to benefit from posture improvements just as much. Thus, future work should also aim to address male users.

USABILITY As discussed in Chapter 6, the usability of the latest prototype was generally considered high. However, we did not completely address the clothing interaction paradigm. Using clothing related interactions could improve future prototypes. Since attiring the device was considered a big hassle, one idea that comes to mind is to add buttons or hooks and eyes to the next iteration. These could not only make attiring easier, but simultaneously serve as an interface to, e.g., turn the device on or off or to trigger calibration.

COMFORT The warmth of the current prototype was criticised during evaluation. It is recommendable to change the material of the garment. In particular, a more breathable fabric would be desirable. Current ideas for this include both natural materials such as Merino wool, and modern engineered high-tech fibres. Using different fabric can also help address the tightness issue. In future iterations, it is advisable to combine different materials that allow the garment to be tight only at the places where it is really necessary - the sensor location, and to be more loose and comfortable elsewhere. A similar approach has shown potential during the specification phase by adding a tight rubber band to a comfortable shirt. However, we did not fully integrate it then, which made attiring tiresome.

DURABILITY This was the key weakness of the current prototype. To ensure washability, which is one aspect of durability, all electronics have been detachable. This, however, led to issues with cables breaking. In a future version, electronics should be completely integrated to avoid loose cables. To develop a consumer-ready product, increasing durability is imparative.

FORM FACTOR, AESTHETICS AND FASHION The design of the shirt itself could be improved in order to ensure perfect sensor positioning and thus functionality. Appendix **??** shows some ideas on how to achieve this in future iterations. While aesthetics was not considered an important aspect by our participants, we still feel that the project could benefit from additional knowledge in fashion design when it comes to fit and look.

TECHNOLOGY There are several aspects for improvement of the technology. Apart from the aforementioned integration into the textile, which would benefit from printed circuit boards instead of hand-soldered ones, there is still room for improvement in the sensor. The evaluation revealed that the chosen sensor was not reliable in extreme cases of poor posture, and it needed to be positioned quite precisely to function properly. For future iterations, we recommend to use a bend sensor that measures over the complete length of 15 cm, which was the furthest flexpoint found during specification. Further, the suggested improvements of adding visual battery status and performance indicators and sitting detection would require additional hardware. From a software perspective, a future iteration should include the recommended trainings schedule that increases usage every day in small steps.

7.1.2 Research

Looking at the research outcomes of this work, it can be stated that the results are promising indicators, but not completely reliable given the small sample size and insufficient duration of the study. Once a more durable product is developed, it would be recommendable to repeat the study with more participants, and more time. Since the data collection using the prototype itself was not successful, one should consider whether to omit this part of the study or to guarantee a reliable data collection by testing the device beforehand over the envisioned time span. Further, it might be useful to have a physiotherapist present at the device hand-over to teach participants correct posture. We still believe that a long term 'in the wild' study is necessary to allow concrete statements about posture improvement, as opposed to short term observations made in laboratory environments.

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A | SOFTWARE

```
// Posturise, Version for Long-Term Study
//
// Hall-sensor magnet hinge for posture detection
// TinyRTC + MicroSD for data logging
// 2-3.6V vibration motor for feedback

// Libraries used
#include <Wire.h>
#include "RTClib.h"
#include <SPI.h>
#include <SD.h>


RTC_DS1307 rtc;

// Pins used
const int chipSelect = 8;
const int sensor = A0;
const int motor = 3;
const int led = 4;
const int button = 5;

// variables for sensor readings
int sensorval;
int minval, maxval, thresval;
const int sensorInterval = 300;
unsigned long currentMillis = 0;
unsigned long previousSensorMillis = 0;
unsigned long starttime;

int buttonval;
int buttonState = 0;         // current state of the button
int lastButtonState = 0;     // previous state of the button
int debounce = 500;
unsigned long buttonToggleMillis = 0;
unsigned long snoozeMillis = 0;
boolean snooze = false;

// variable for data logging
String dataString = "";
String startTimeString = "";
String endTimeString = "";

// states of posture state machine
#define GOOD      0
```

```
#define MAYBEPOOR 1
#define POOR      2
#define CALIBRATE 3
uint8_t posture_fsm_state = CALIBRATE;
unsigned long maybeMillis = 0;
String calibrationString = "";

// states of feedback state machine
#define FDBCK_OFF       0
#define FDBCK_ON        1
#define FDBCK_PAUSE     2
uint8_t feedback_fsm_state = FDBCK_OFF;
unsigned long feedbackMillis = 0;
unsigned long feedbackPauseMillis = 0;
int feedbackDuration = 3000;
int pauseDuration = 10000;

// variables for idle days
boolean idleDay = false;
DateTime firstObservation (2015, 11, 19, 0, 0, 0);
DateTime secondObservation (2015, 12, 3, 0, 0, 0);


void setup() {
  // Core Functionality
  pinMode(sensor, INPUT);
  pinMode(led, OUTPUT);
  pinMode(button, INPUT_PULLUP);
  pinMode(motor, OUTPUT);
  analogWrite(motor, 0);

  // Calibration
  minval = 1024;
  maxval = 0;
  starttime = millis();

  // Serial Communication
  Serial.begin(9600);
  //  while (!Serial);
  Serial.println("Posture shirt");
  // RTC
  if (! rtc.begin()) {
    Serial.println("Couldn't find RTC");
    while (1);
  }
  if (! rtc.isrunning()) {
    Serial.println("RTC is NOT running!");
    // following line sets the RTC to the date & time this sketch
        was compiled
    rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
  }

  // SD Card
```

```
  Serial.print("Initializing SD card...");

  // see if the card is present and can be initialized:
  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");
    // don’t do anything more:
    return;
  }
  Serial.println("Card initialized.");
  checkIdleDay();
}

void loop() {
  currentMillis = millis();
  checkIdleDay();
  checkSnooze();

  // Posture state machine
  switch (posture_fsm_state) {

    case CALIBRATE:
      if (millis() < starttime + 10000) {
        calibrate();
        digitalWrite(led, HIGH);
      }
      else {
        // Go to next state
        posture_fsm_state = GOOD;
        digitalWrite(led, LOW);
      }
      break;

    case GOOD:
      if (sensorval > thresval) {
        posture_fsm_state = MAYBEPOOR;
      }
      feedback_fsm_state = FDBCK_OFF;
      Serial.println("good posture");
      digitalWrite(led, LOW);
      maybeMillis = 0;
      break;

    case MAYBEPOOR:
      if (maybeMillis == 0) {
        maybeMillis = millis();
      }
      if (millis() < maybeMillis + 15000) {
        if (sensorval < thresval) {
          posture_fsm_state = GOOD;
        }
        else {
          posture_fsm_state = MAYBEPOOR;
        }
```

```
    }
    else {
      posture_fsm_state = POOR;
    }
    feedback_fsm_state = FDBCK_OFF;
    Serial.println("maybe poor posture");
    digitalWrite(led, HIGH);
    break;

  case POOR:

    if (dataString == "") {
      logDataString();
    }
    if (!idleDay && !snooze && feedback_fsm_state == FDBCK_OFF)
         {
      feedback_fsm_state = FDBCK_ON;
    }
    if (sensorval < thresval) {
      writeData();
      posture_fsm_state = GOOD;
    }
    Serial.println("poor posture");
    digitalWrite(led, HIGH);
    break;
}

// Feedback state machine
switch (feedback_fsm_state) {
  case FDBCK_OFF:
    analogWrite(motor, 0);
    //      Serial.println("no feedback");
    feedbackMillis = 0;
    break;

  case FDBCK_ON:
    feedbackPauseMillis = 0;
    // vibrate twice shortly
    //      Serial.println(feedbackMillis);
    if (feedbackMillis == 0) {
      feedbackMillis = millis();
      Serial.println(feedbackMillis);
    }
    if (millis() < feedbackMillis + feedbackDuration) {
      if (millis() < feedbackMillis + feedbackDuration / 3 ||
          millis() > feedbackMillis + (feedbackDuration * 2 /
          3)) {
        analogWrite(motor, 200);
        Serial.println("feedback, motor on");
      }
      else {
        analogWrite(motor, 0);
        Serial.println("feedback, motor off");
```

```
        }
      }

      else if (millis() > feedbackMillis + feedbackDuration) {
        analogWrite(motor, 0);
        feedback_fsm_state = FDBCK_PAUSE;
        Serial.println("feedback time over");
      }
      break;

    case FDBCK_PAUSE:
      feedbackMillis = 0;
      //      analogWrite(motor, 0);
      if (posture_fsm_state == GOOD) {
        feedback_fsm_state = FDBCK_OFF;
      }
      else {
        if (feedbackPauseMillis == 0) {
          feedbackPauseMillis = millis();
        }
        if (snooze) {
          feedback_fsm_state = FDBCK_OFF;
          }
        if (!snooze && millis() > feedbackPauseMillis +
            pauseDuration) {
          feedback_fsm_state = FDBCK_ON;
        }
        Serial.println("feedback pause");
        break;
      }

  }
  readSensor();
  delay(2);
}

//==========================================
// check if the shirt gives feedback today
void checkIdleDay() {
  DateTime now = rtc.now();
  if (now.day() == firstObservation.day() || now.day() ==
      secondObservation.day()) {
    idleDay = true;
    Serial.println("Idle day, no feedback");
  }
  else {
//    Serial.println("Active day, feedback");
  }
}

//==========================================
// check if feedback was snoozed
void checkSnooze() {
```

```
  buttonState = digitalRead(button);
  if (buttonState == LOW && lastButtonState == HIGH && millis() -
       buttonToggleMillis > debounce) {
    if (!snooze) {
      snooze = true;
      Serial.println("snooze on");
      snoozeMillis = millis();
    }
    else {
      snooze = false;
      Serial.println("snooze off");
    }
    buttonToggleMillis = millis();
  }
  lastButtonState = buttonState;
  if (snooze && millis() > snoozeMillis + 3600000) {
    Serial.println("snooze expired");
    snooze = false;
  }
}

//========================================
// calibrate sensor values
void calibrate() {
  sensorval = analogRead(sensor);
  if (sensorval < minval) {
    minval = sensorval;
    Serial.println("Min");
    Serial.println(minval);
  }
  if (sensorval > maxval) {
    maxval = sensorval;
    Serial.println("Max");
    Serial.println(maxval);
  }

  // take as threshold some value between min and max
 // thresval = minval + ((maxval - minval) / 4 );
    thresval = maxval - ((maxval - minval)/3);
}


//========================================
// read sensor values each sensorInterval
void readSensor() {
  if (currentMillis - previousSensorMillis >= sensorInterval) {
    sensorval = analogRead(sensor);
    Serial.println(sensorval);
    previousSensorMillis += sensorInterval;
  }
}

//========================================
```

```
// log data

void logDataString() {
  // Start Time
  DateTime now = rtc.now();
  // String for data logging


  String theyear = String(now.year(), DEC);
  String themonth = String(now.month(), DEC);
  String theday = String(now.day(), DEC);
  String thehour = String(now.hour(), DEC);
  String themin = String(now.minute(), DEC);
  String thesec = String(now.second(), DEC);
  //Put all the time and date strings into one String
  startTimeString += String(theyear + "/" + themonth + "/" +
      theday + "," + thehour + ":" + themin + ":" + thesec );

  dataString += startTimeString;
  dataString += ",";
  dataString += String(minval);
  dataString += ",";
  dataString += String(maxval);
  dataString += ",";
  dataString += String(thresval);
  dataString += ",";
  dataString += String(sensorval);
  dataString += ",";
}


//==========================================
// write data to SD card
void writeData() {
  DateTime now = rtc.now();
  // String for data logging
  String thisyear = String(now.year(), DEC);
  String thismonth = String(now.month(), DEC);
  String thisday = String(now.day(), DEC);
  String thishour = String(now.hour(), DEC);
  String thismin = String(now.minute(), DEC);
  String thissec = String(now.second(), DEC);
  //Put all the time and date strings into one String
  endTimeString += String(thisyear + "/" + thismonth + "/" +
      thisday + "," + thishour + ":" + thismin  + ":" + thissec )
      ;

  dataString += endTimeString;
  File dataFile = SD.open("datalog.txt", FILE_WRITE);
  if (dataFile) {
    dataFile.println(dataString);
    dataFile.close();
    // print to the serial port too:
```

```
    Serial.println("Final data string");
    Serial.println(dataString);
  }
  // if the file isn’t open, pop up an error:
  else {
    Serial.println("error opening datalog.txt");
  }
  String dataString = "";
}
```

B | CONSENT FORMS

UNIVERSITY OF TWENTE.

Wearable Intervention for Posture Improvement

Consent Form

The University of Twente and the Department of EEMCS support the practice of protecting research participants' rights. The information in this consent form is provided so that you can decide whether you wish to participate in our study. It is important that you understand that your participation is considered voluntary. This means that even if you agree to participate you are free to withdraw from the experiment at any time, without penalty.

The aim of this study is to collect data on the effect our prototype has on people's posture. The study takes places over the course of three weeks, during which we ask you to wear the prototype as often as you can, preferably every day of the work week.

Contact information

I. Pfab, BSc (lead investigator)
C.J.A.M Willemse, MSc
Dr. A.H. Mader
Prof.dr. D.K.J. Heylen

Human Media Interaction group
Drienerlolaan 5
7522 NB Enschede
The Netherlands
http://hmi.ewi.utwente.nl/
053-4893740 (Secretary)
x.pfab@student.utwente.nl

The prototype records when you slouch while wearing it. Every work day, you will be asked to answer a short questionnaire that asks you about your mood. The data collected will be used for purposes of this research only. It will only be made public in a processed and anonymous manner.

During the study, video or audio may be recorded for review purposes of the research. This identifiable data will be made available only to members of the project team. It will be stored carefully for at most five years (November 2020).

This experiment poses no known risks to your health. If you have any questions not addressed by this consent form, please do not hesitate to ask. Please also note that you can get in touch with the lead researcher at any time during the course of the study if you have further questions or difficulties with your prototype.

Declaration of consent (please tick each checkbox if you consent)

◯ **1.** I agree to participate in this study

◯ **2**. I have read the instructions above and understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

◯ **3**. I understand that my identifiable data is recorded for research purposes as described above, and can be stored until November 2020.

___________________________ Name and signature participant

__________________ Date

Figure 43: Consent Form 1

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Wearable Intervention for Posture Improvement

Consent for usage of video recordings

Contact information

I. Pfab, BSc (lead investigator)
C.J.A.M Willemse, MSc
Dr. A.H. Mader
Prof.dr. D.K.J. Heylen

Human Media Interaction group
Drienerlolaan 5
7522 NB Enschede
The Netherlands
http://hmi.ewi.utwente.nl/
053-4893740 (Secretary)
x.pfab@student.utwente.nl

During the intake and closing meeting of the experiment, we secretly took video recordings of your seated posture. It was necessary to do this secretly to prevent adjustment. Of course, we would not use this data without your consent.

The aim of these recordings was to have visual data to augment the data recorded by the prototype. We would like to show them to a trusted physiotherapist, who will analyse your posture in both recordings to see whether your posture changed.

If you agree to let us use these recordings, they will be made available only in the scope you agree to. You can chose to allow either review only by the project team, or to make the recordings available for presentation purposes as well. If you decide not to, we will destroy the recordings immediately. Else, they will be anonymised, so your face is not recognisable. They then will be stored carefully for at most five years (November 2020).

Declaration of consent (please tick each checkbox if you consent)

○ **1.** I agree to review of my video recordings by the project team

○ **2**. I agree to usage of my video recordings for presentation at the University of Twente

○ **3**. I agree to usage of my video recordings for public publication, e.g. on YouTube

○ **4**. I understand that my video recordings can be stored until November 2020.

__________________________ Name and signature participant

_________________ Date

Figure 44: Consent Form 2

C INFORMATION BROSCHURE AND PROTOTYPE MANUAL

How to use the prototype

For the prototype to work properly, it is important that you know how to use it. Here are some helpful tips:

- You can wear the prototype under your everyday clothing
- The prototype is really tight, so it might be tricky to attire. Rolling it up can help making this easier
- The sensor should be located central on your belly, between the lower end of your sternum and your belly button. This is important for it to work properly!
- Except for the first and last day, the prototype will vibrate if you slouch
- If you are in a situation where you would not like to get feedback, you can snooze for an hour by pressing the button
- Try to charge the battery every night to ensure youre not running out. You can use a standard microUSB charger. If you do not own one, ask the researcher

UNIVERSITY OF TWENTE.

Wearable Intervention for Posture Improvement

Information Sheet

This document is for you to take home. It contains some information about the study as well as the prototype.

- The aim of this study is to collect data on the effect our prototype has on people's posture over a few weeks
- Your participation in this study is voluntary, so you can withdraw your participation at any time
- The study begins and ends with a meeting which take approximately one hour each
- You will receive a prototype to take home with you. Please wear the prototype as often as you can, preferably every day of the work week
- During the first and last day of the experiment, the prototype will only record your behaviour and not give feedback. All other days, it will notify you if you slouch by vibrating in the back
- Every work day, you will be asked to answer a short questionnaire that asks you about your mood. Please answer these questions honestly, we will treat your data confidentially
- Each Friday, we will pick up your prototype to wash it and make sure it works properly. You will get it back the following Monday. If you'd like to wash it yourself in between, please make sure to remove the electronics carefully
- You can get in touch with the lead researcher at any time during the course of the study if you have further questions or difficulties with your prototype!
- If you have any other queries, complaints or comments about the research, you can contact the secretary of HMI

Contact information

I. Pfab, BSc (lead investigator)
C.J.A.M Willemse, MSc
Dr. A.H. Mader
Prof.dr. D.K.J. Heylen

Human Media Interaction group
Drienerlolaan 5
7522 NB Enschede
The Netherlands
http://hmi.ewi.utwente.nl/
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x.pfab@student.utwente.nl

Figure 45: Information Sheet

D | DAILY QUESTIONNAIRE

Topic	Item
Usage behaviour	Did you wear your prototype today?
	If not, can you tell us why?
	If you wore it, did you turn it off at some points during the day?
	Why / in which situations did you turn it off?
Mood assessment	Today I felt.. on a 7-point scale from 'very tired' to 'very awake'
	Today I felt.. on a 7-point scale from 'very content' to 'very discontent'
	Today I felt.. on a 7-point scale from 'very agitated' to 'very calm'
	Today I felt.. on a 7-point scale from 'very full of energy' to 'very much without energy'
	Today I felt.. on a 7-point scale from 'very unwell' to 'very well'
	Today I felt.. on a 7-point scale from 'very relaxed' to 'very tense'
Additional questions	Would you like to schedule a call or meeting with us?
	Would you like to schedule a call or meeting with us?

Table 6: Items of the Daily Questionnaire

E | INTERVIEW QUESTIONS

Topic	Item
Demographic	How old are you?
	What is your profession?
Sedentary behaviour	How many hours per day do you sit?
	During these hours, how frequently do you get up and move? (e.g. coffee breaks)
	How many hours per day are you active?
Motivation for posture improvement	How often do you think about your posture?
	In which situations do you think about your posture?
	Why would you like to improve your posture?
	Do you feel your posture has negative influence on your day sometimes? Can you give examples?
	In which aspects would you like to improve your standing posture?
	In which aspects would you like to improve your seated posture?

Table 7: Questions asked during the intake interview

Topic	Item
Posture awareness	How often do you think about your posture? Is that different compared to the last interview?
	In which situations do you think about your posture? Is that different compared to the last interview?
Perceived posture improvement	Did the prototype enable you to improve your posture? In what way?
	Did the prototype enhance your well-being? In what way?
	You experienced posture-related issues before, did that change?
	Do you think this effect will stay with you, now that you are not wearing the prototype anymore? For how long?
Usage behaviour	For how many days did you wear the prototype?
	On these days, how many hours did you wear it on average?
	Do you feel that was appropriate to change your behaviour?
	Do you think a different usage pattern could have helped better / just as well? If so, which and why?
	How did you feel when putting on the prototype every morning?
Ease of use	Was it easy for you to use the prototype?
	Which aspects were particularly easy / difficult?
	Was the interaction with the prototype clear and understandable?
	Do you have any suggestions how to make it easier to use?
Intention to use	Would you like to continue wearing a shirt with this functionality?
	Why? What would need to change so you would like to?

Table 8: Questions asked during the closing interview

F SCRIPT BRIEFING

"As my master's project, we have developed a new method to detect poor posture and provide immediate feedback. The experiment at hand aims to see whether this helps people to improve their posture. Because changing ones posture takes some time to build up the habit, but also the muscle memory, the experiment will run over the course of three weeks.
The procedure is as follows: we start today, with this briefing. Then, if you agree to participate, you have to sign a consent form. After that we will do a short interview, in which we talk a bit about you, and why you want to improve your posture. Then you will receive your prototype, you can try it on and I will explain you how to use it. We can make adjustments if necessary. After that, you can take it home.
During the next three weeks, you are asked to wear your prototype as much as possible, ideally every workday. You can simply wear it below your usual attire. Each Friday, I will pick up your prototype, to wash it and ensure everything is working properly. You will receive it back each Monday.
At the end of each workday, you will receive an email with a short questionnaire. It should not take more than three minutes of your time. This also gives you the opportunity to schedule a meeting or call with me in case there are any issues or open questions.
At the end of the three weeks, we will do a closing interview, in which we talk about your experience with the prototype. Do you have any questions so far?"

G SKETCHES FUTURE ITERATIONS

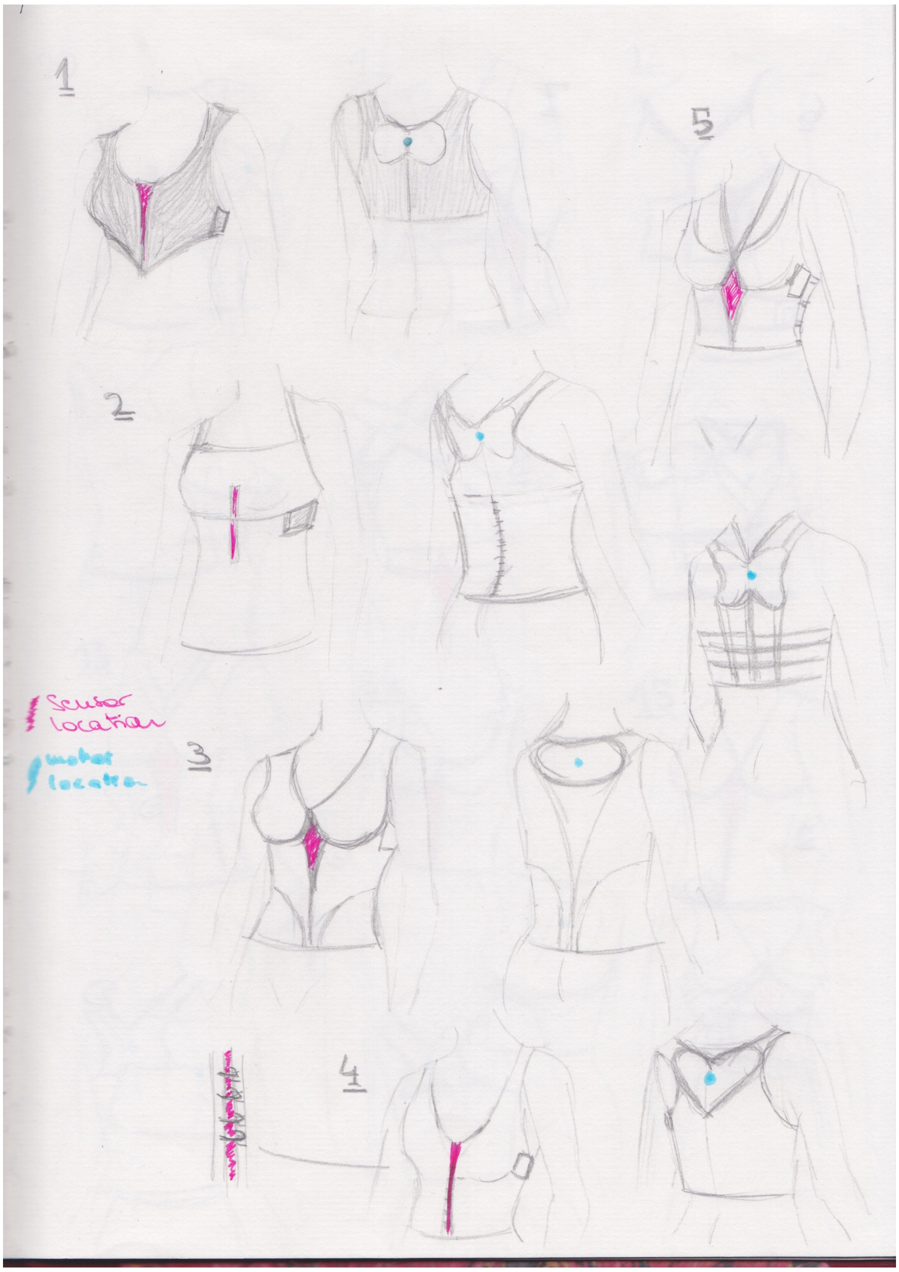

Figure 46: Sketches 01-05

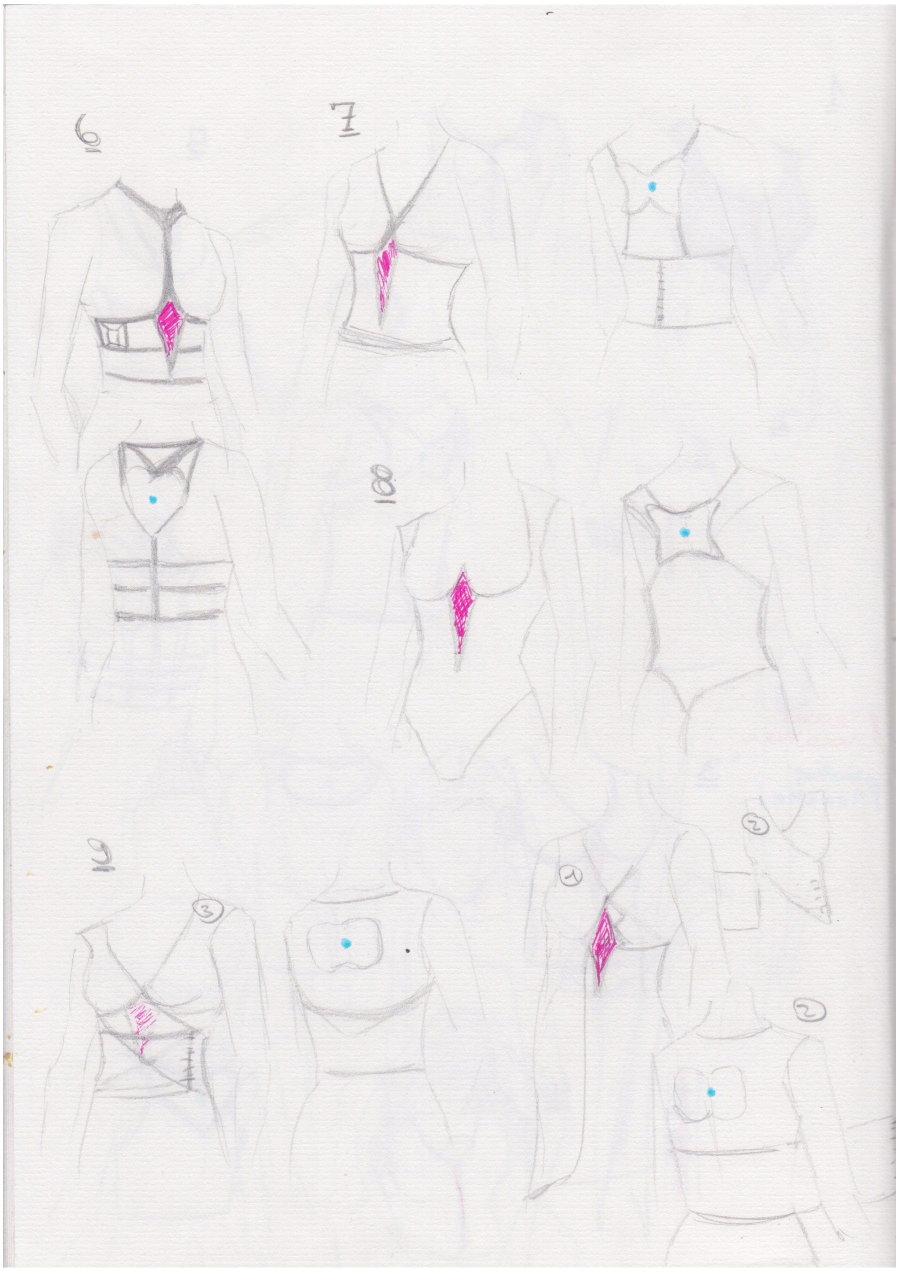

Figure 47: Sketches 06-09

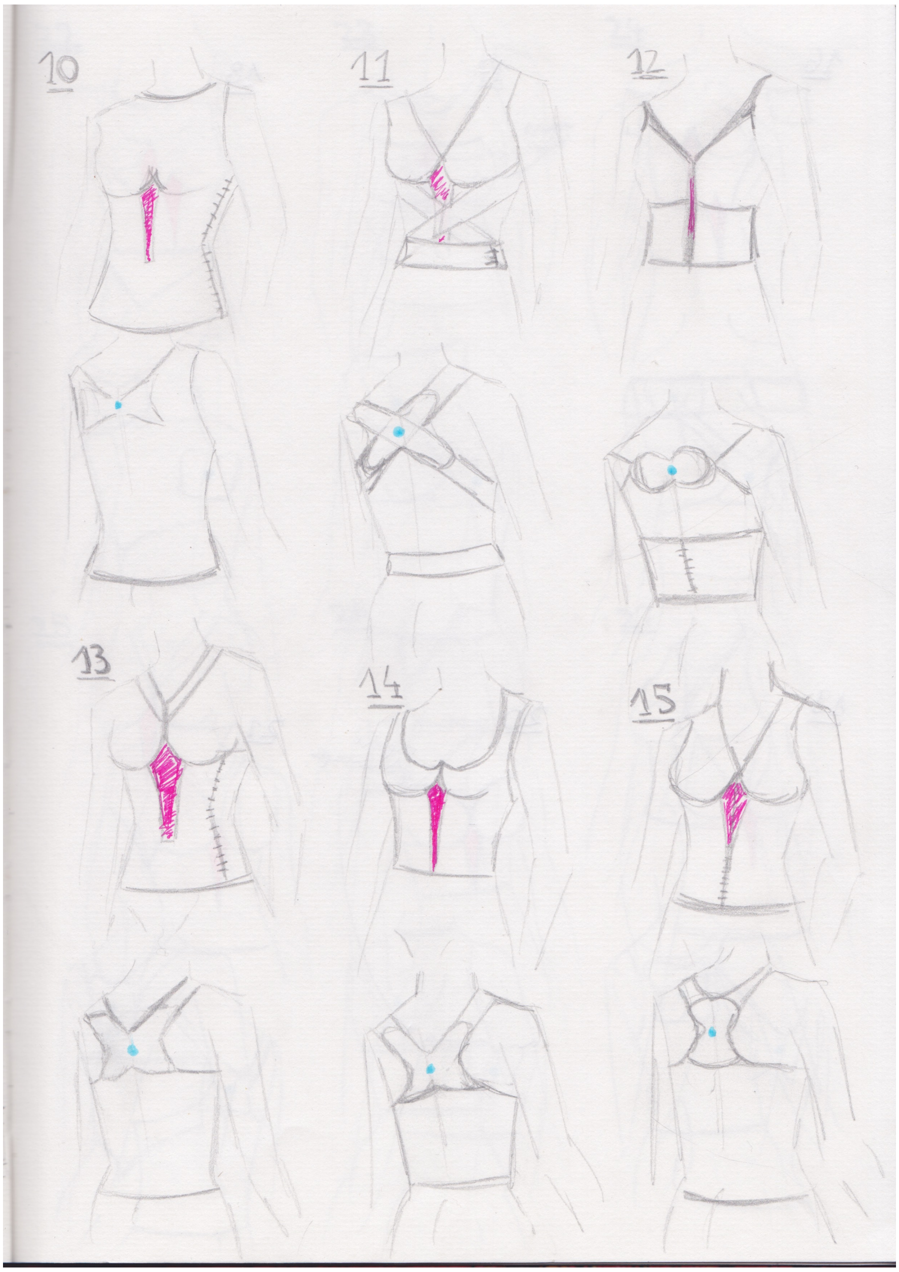

Figure 48: Sketches 10-15

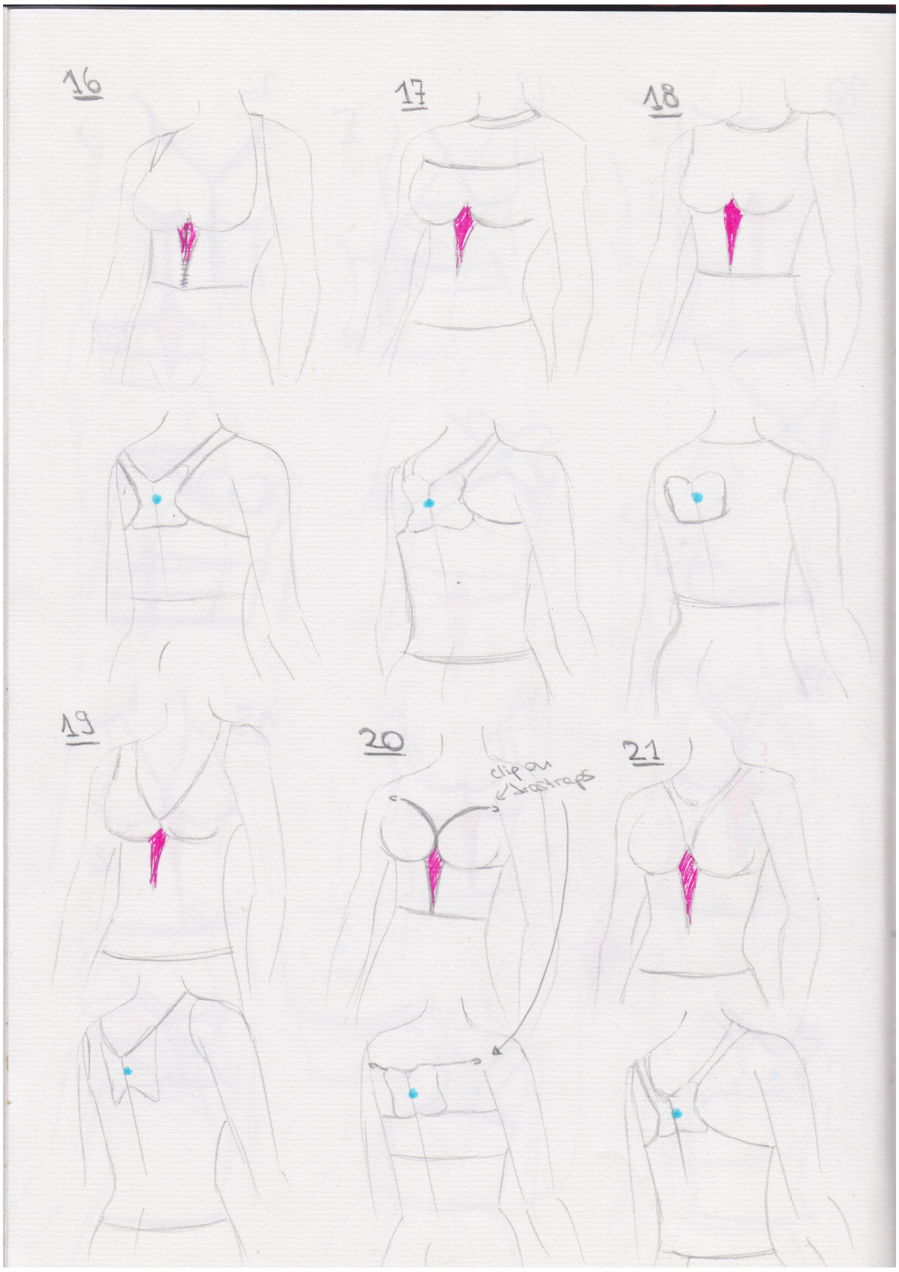

Figure 49: Sketches 16-21

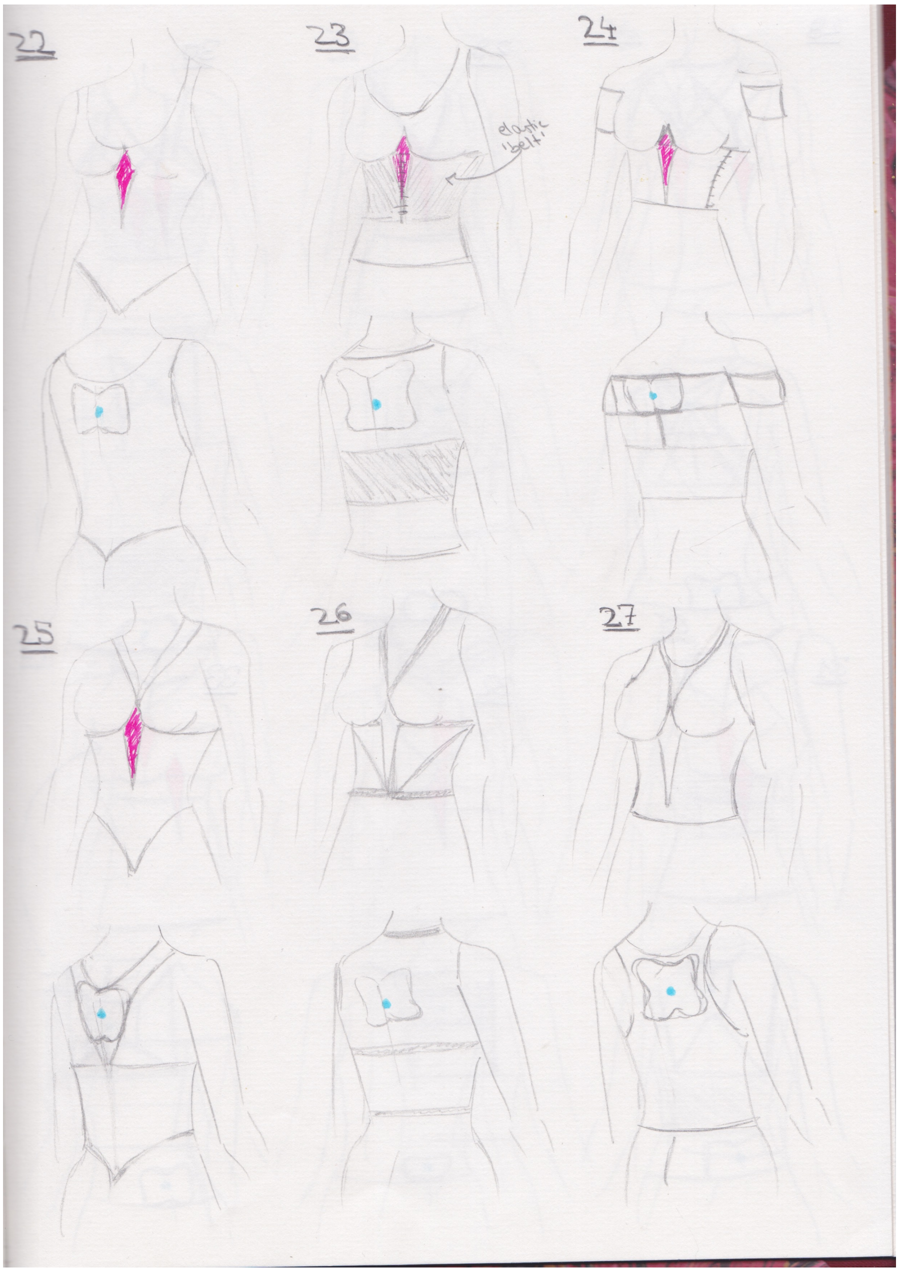

Figure 50: Sketches 22-27

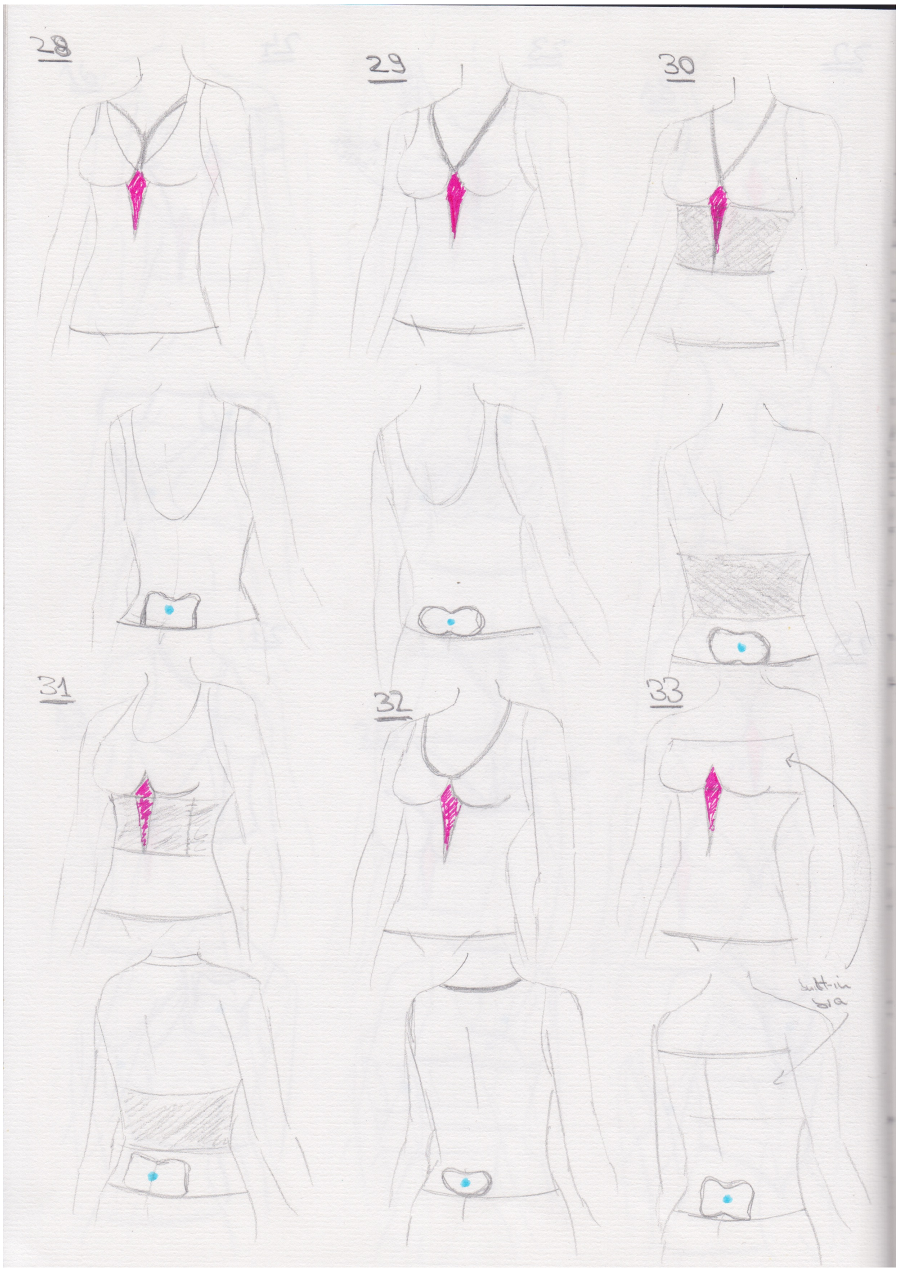

Figure 51: Sketches 28-33

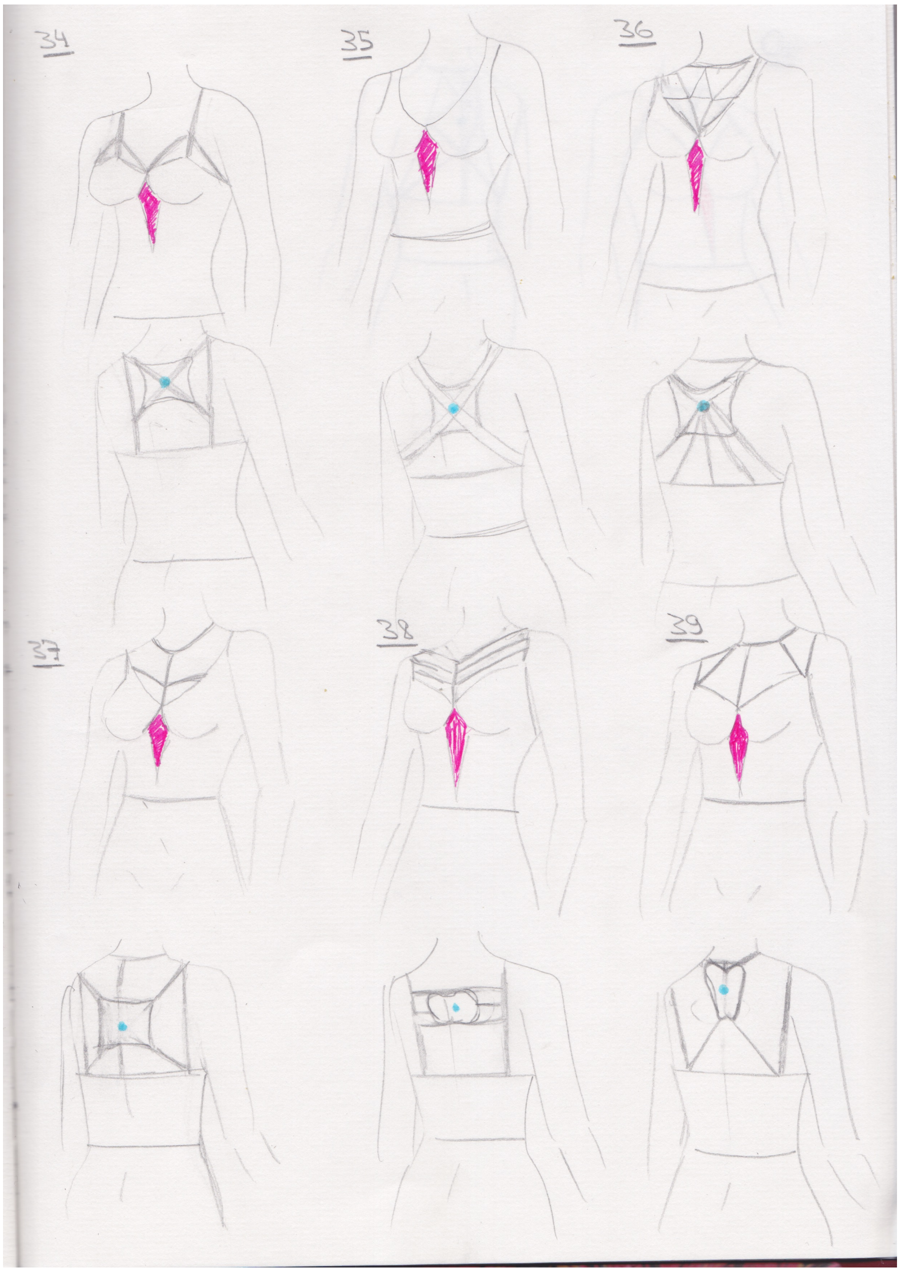

Figure 52: Sketches 34-39

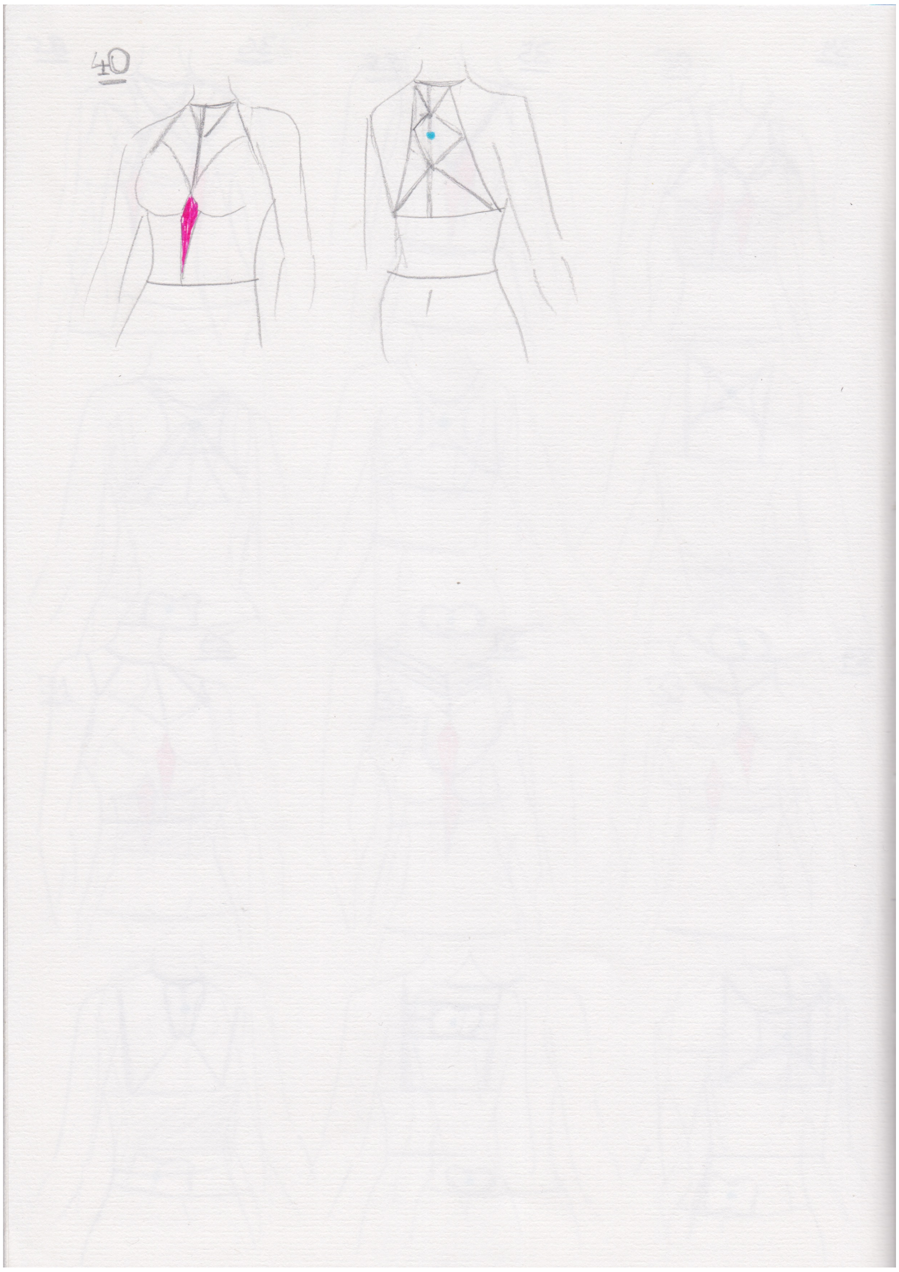

Figure 53: Sketches 40