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**Faculty of Electrical Engineering,
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Haptic Feedback in a Posture Correcting Wearable

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B.Sc. Thesis Creative Technology

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Abstract

A posture correcting wearable that uses haptic feedback is designed from an autoethnographic point of view. In order to do this, research has been done in the domains of haptic feedback, postures, and wearable technology. Based on the state of the art research, hypothesis have been drawn up, which are tested by executing several experiments. From these experiments several insights have been gained.

While a poor posture is an accumulation of events, that start with the tilting of the pelvis, posture is best measured at the pelvis. This is done with the use of two accelerometers, one at the top, and one halfway the pelvis. To correct the posture of the user, haptic feedback is applied at the back. In order to give intuitive haptic feedback, uplifting patterns, made by three vibration motors in vibration dispersing material, are used. Two pieces of vibration dispersing material with each three vibration motors, are placed at both sides of the spine just above the pelvis. This placement is used while the feedback is then applied on the big muscles that are responsible for the positioning of the pelvis.

All these elements need to be embedded in a wearable that does not obstruct the user in its actions. This is best done by creating a wearable that is tightly fitted around the body, where electronics are tucked away neatly, and which requires nothing else from the user than wearing it and attaining a correct posture.

Acknowledgements

For this project I would like to thank my supervisor Angelika Mader. She has been a very enthusiastic, supporting, and motivating supervisor. Weekly meetings made sure that each week was filled productively. Her curiosity into the subject and into my work made it pleasant to share freshly gained knowledge, and gave me the space to share my honest opinion on it. I am very grateful for her enthusiastic involvement and support during this project.

Another person who has really meant a lot for this project, and who I would like to thank for that, is the physiotherapist Christine Hulst. Without her professional knowledge, I would not have had such a wide perception of, and feeling for postures. In a time slot of approximately two and a half hour, she taught me everything that I needed to know, in order to execute a bachelor project which lies for one third outside of my professional domain.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 The project

Haptic feedback in wearable technology: the first concept for a graduation project of the bachelor Creative Technology. A very broad subject, while haptic feedback as well as wearable technology can be used in many different ways. To narrow down the topic, there is chosen for haptic feedback in a wearable device for the coaching of the seated posture. Looking at this as the main aim of the project, it can be divided into three topics: *haptic feedback*, *wearable technology* and *posture correction*.

Haptic feedback is computer controlled feedback that is perceived by the human body as the feeling of touch [1]. This feedback and its effect is attained by a device that exchanges forces from a computer to an user [2]. Wearable technology is, as the name already implies, technology that can be worn by someone. This can be a device that is clipped on clothing, but it can also be the clothing itself. A big advantage of the combination of haptic feedback and wearable technology, is that the feedback can be applied anywhere on the body. This creates the possibility to give the user's feedback with a low cognitive load, to disturb them as little as possible. There are many different postures that can be corrected or supported, this project focuses on the seated posture. With the use of haptic feedback in wearable technology, people can be reminded or even corrected on their poor postures. When feedback is applied at the correct spot, the cognitive load can be decreased, which makes the feedback more intuitive [3].

1.2 Problem statement

Technology is a large part of our current society. Due to all the electronic devices such as smartphones, tablets and laptops, people are busier than ever. Because of this constant stream of information and to-dos, simple actions such as keeping a correct posture are completely forgotten. It is only when the negative effects of this incorrect posture are shown, in the form of a painful back, that people start to think about their posture. This is a personal problem that is also seen with a lot of other people. In order to prevent this painful back, haptic feedback in wearable technology is going to be used to correct the seated posture of the user.

Studies [4] have shown that people are able to perform multiple tasks at the same time, as long as they do not use the same cognitive system, for example the auditory and visual system. Based on this, there is assumed that when executing computer work, haptic feedback is superior over visual feedback, while the visual system is already used for the computer work.

1.3 Research questions

As a start of this project, the research question is formulated as: *How to design haptic feedback in a posture correction wearable from an autoethnographic perspective?*

In order to answer the big research question, knowledge has to be gained in the areas of haptic feedback, wearable technology and posture correction. To attain this knowledge, several subquestions are composed:

1. What possibilities for haptic feedback are there?
2. What is a poor posture?
3. What constructs a good posture?
4. How to measure a good and poor posture in a wearable?

1.4 Set up

1.4.1 Autoethnographic design method

This project has an autoethnographic design method approach. This is a way of designing based on research done on the researcher herself. This research is executed via studies that pursue traditional ethnographic research guidelines, but take place within the researchers' own environment. This has the advantage that small selectively focused research cycles can be executed [5]. Another advantage, with regard to wearables is for example, that clothing sizes do not have to be taken into account.

A traditional ethnographic researcher tries, with his research, to become an insider in the research topic. An autoethnographic researcher does not have to try to become this, while she already is the insider of the topic, because the context is her own [6]. That autoethnographic researchers find themselves in the center of the focus, becomes clear when looking at the observation element of research. Observation of participants is one of the most important aspects of research, no matter of its kind [5]. With ethnographic research these observations can become an obstacle, while permission of the observed people needs to be gained by the researcher, for him to become a participant in their world. Autoethnographic researchers do not have this obstacle while they are already fully immersed in the situation of the research its focus [5].

Autoethnography enables the researcher & designer to dive deeper into the topic, by which more intuition and insight in the problem is gained. With these insights and intuitions, a more personalized and meaningful design or prototype can be made. So overall, a more in depth experience is achieved.

All these aspects together result in the creation of a whole new perception on the design space. Autoethnographic design is the first step in the design process. Findings from an autoethnographics design point of view can be further explored in additional research. User groups should then be taken into account, by which a design can be created that is applicable a large range of people.

There is chosen to use this design method so that a very intuitively working wearable can be designed, while the researcher & designer exactly knows how everything is perceived, rather than deriving this from test person their responses. This results in the possibilities to make small research cycles, that can easily be implemented in the design.

1.4.2 Report

This report contains all the research that is executed, knowledge that is attained, and insights that are gained. To get started on postures, an interview is executed to gain insights into postures and everything around it, this interview is stated, next to the rest of the state of the art, in chapter 2. Based on the insights gained from the state of the art, experiments are carried out that filled the ideation phase, depicted in chapter 4. The conclusions from all the experiments of the ideation phase are the base for the prototype wearables that are designed (chapter 5), created (chapter 6) and evaluated (chapter 7). While this project follows an autoethnographic design method, a small reflection on this is stated in the discussion, depicted in chapter 8. A conclusion is drawn from thew whole project, see chapter 9. And because research is never done, chapter 10 contains several possibilities and recommendations for future research.

Chapter 2

State of the Art

Desiging a posture correcting wearable with the use of haptic feedback from an autoethnographic perspective requires some research into several domains. This research is primarily done into the domains of postures and haptic feedback. There is a lot of literature written about correct postures, but to get a good insight into what good and poor postures are, an extensive interview about this is carried out with a physiotherapist. To research the effect of haptic feedback on the human body and mind, a posture correcting device called Lumo Lift is worn. This is at the same time also the first step in getting familiar with the use of wearable technology.

2.1 Interview physiotherapist

To gain knowledge and insights into the correct posture of the human body, an interview with the physiotherapist Christine Hulst is conducted. A more elaborative, dutch version of this interview can be found in appendix I.

2.1.1 Correct and incorrect posture

A poor posture is an accumulation of events. In order to explain how a poor posture is formed, and how to improve it, first the correct posture will be explained. A correct posture starts with a neutral positioned pelvis which means that it is positioned up straight. The spine is connected to the pelvis and goes from a slight lumbar lordosis, to thoracic kyphosis, to a cervical lordosis, see figure 2.1. The cervical vertebrae are placed on top of each other, where the head balances on the whole spine. Finally, the scapulae are at the rear side of the back as shown in figure 2.2(a.).

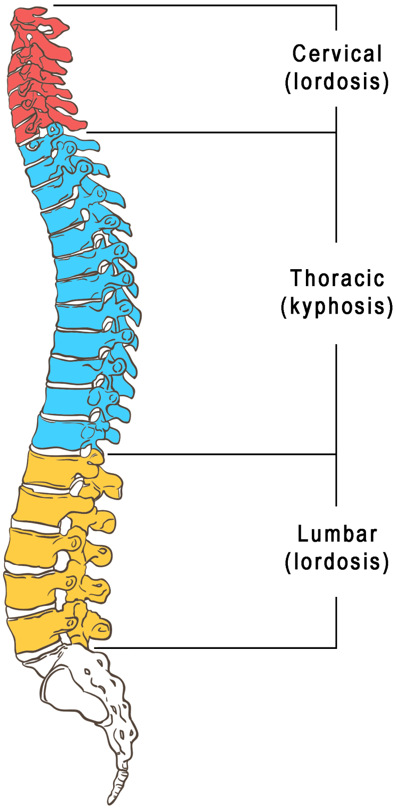


Figure 2.1: Cervical, Thoracic & Lumbar part of the spine

The power of a correct spine lies in its form: lordosis, kyphosis, lordosis, see figure 2.1. Due to this a spring system is formed. Instead of a straight stick which would break when a large pressure is put on it, the spine can now take some weight because it can bounce slightly due to its spring behavior.

Figure 2.2: (a.) Correct scapulae posture (b.) Incorrect scapulae posture

Knowing what a correct posture is, a poor posture can be explained. A poor posture starts at the pelvis which is tilted backwards, see figure 2.3(b.). Because the lumbar part of the spine is connected to the pelvis, it is pulled backwards. Due to this the center of gravity moves backwards, in order to prevent falling back, the thoracic spine compensates by bending forwards. This bending forward causes anterior positioning of the cervical spine and head. The head is now nodded downwards, but in order to be able to properly look forward the chin is extended forwards by which the head is tilted, this is called forward heading. Another effect of the new position of the thoracic spine is that the lower extremities of the shoulder-blades (inferior angle of the scapulae) rotate outwards, see figure 2.2(b.).

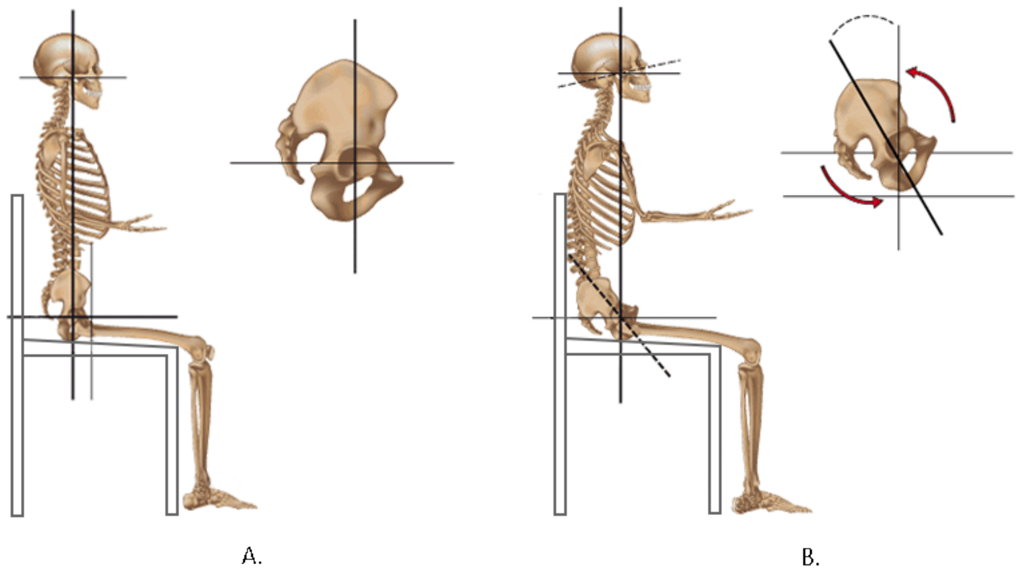


Figure 2.3: (a.) Pelvis in neutral position (b.) Pelvis tilted back, designed by TFM

2.1.2 Three steps for a correct posture

A correct posture can easily be attained by executing the three steps described in this section.

1. Tilt the pelvis to the neutral position which means it is drawn up straight. By tilting the pelvis to its correct state the lumbar spine automatically moves along. The tilting of the pelvis can be externally supported by exercising a pressure which moves from the sacrum up to the lumbar vertebrae.

2. Move the inferior angle of the scapulae down and slightly inwards. A mnemonic aid to for this is that they should point in the direction of a bra clasp. The muscle that has to execute this movements is the trapezius.

3. Place all the cervical vertebrae on top of each other and let the head balance on the spine. When this step is executed correctly, the crown of the head points upwards.

2.1.3 Muscles

Extrinsic and intrinsic muscles

There are many muscles connected to the spine. All these muscles can be divided into two categories, the extrinsic (big) and intrinsic (small) muscles. Small muscles connect the individual vertebrae together. These muscles are crucial for a correct posture. When comparing them to running, the intrinsic muscles are the marathon runners, they have a large endurance, but cannot deliver high power. Big muscles lay along the entire spine and are connected to all the vertebrae. These muscles are used for fast movements and movements that require a lot of strength. Extrinsic muscles are the sprinters, they can deliver a lot of power, but are not able to deliver this high amount of power for a long period of time. When the body does demand this, the muscles turn sour which makes that spot of the body stiff and painful. An example where this happens a lot, is in the neck. The head is tilted and the chin is extended forwards. The head is approximately five kilograms and when this balances on top of the spine, the body can easily carry it. However, when the head hangs for the body, the moment increases, which requires a lot of strength that only the big muscles can deliver. The problem is that people tend to keep that position for a long time, which is too long for the big muscles and thus causes pain. It is thus very important that a correct posture is attained and that the small muscles do their work properly. They need to have a correct coordination and a large endurance, because they are the ones that need to keep the posture for a long period of time.

In order to get rid of backache complaints that are formed due to an incorrect posture, the small muscles need to be trained. When instead the big muscles are trained, the task of these small muscles are taken over, which leads to even more deterioration of the small muscles. The best way to train small muscles, is to train them in the field. This is done by actively practicing to attain a correct posture when sitting and concentrating on doing this with the small muscles. So making small adjustments on individual vertebra level, an indication for working on this level, is to use little force and only have small motions. This is because the motion of one vertebra is only very small. The back is able to make its big movements because twenty four small movements together, can create a large movement.

Spine and abdomen

At both sides of the spine lie the Erector Spinae, see figure 2.4(a.). These are the big muscles that are connected to Iliac crest of the pelvis and run along the whole spine all the

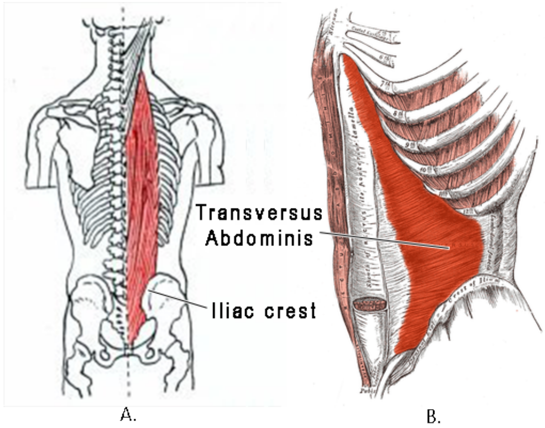


Figure 2.4: (a.) Erector Spinae (posterior) (b.) Transversus Abdominis (anterior)

way up to the neck. They do not only lie along the spine, they are also connected to the transverse process of all the vertebrae, see figure 2.5. Because they are connected to all the vertebrae they also have an influence on all the vertebrae, however, they have the biggest influence on the weakest and most unstable vertebra.

Next to the muscles of the back, the Transversus Abdominis is also essential for a correct posture. It lies around the body as a corset and helps the muscles of the spine to keep the body straight up. When this muscle is well trained, it costs less effort to keep the vertebrae in the correct position, see figure 2.4(b.).

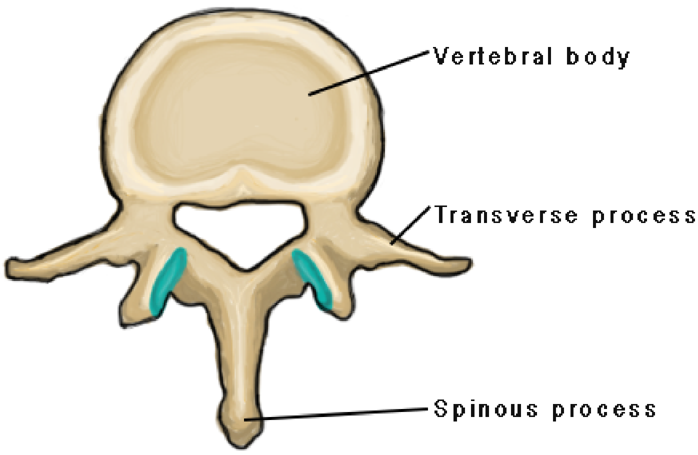


Figure 2.5: Lumbar vertebra L2

2.1.4 Conclusion

The best way to achieve a correct posture, is thus by actively practicing to get and keep the body in the correct posture. This starts with the tilting of the pelvis and thus correctly

positioning the lumbar spine. The triggering of the pelvis can be done by exercising a pressure movement which starts at the sacrum and moves up to the lumbar vertebrae. The shoulders should be positioned so that the inferior angle point downwards and the scapula are at the rear side of the back, rather than turned to the side. The last step is to place the cervical vertebrae on top of each other, and positioning the head on top of that.
Essential for a correct posture are:

- Neutral position pelvis
- Correct lumbar, thoracic and cervical spine position
- The scapula positioned correctly at the back
- Balance the head on top of the spine rather than hang it in front of the body.
- Coordinative and endurance of the intrinsic muscles

2.2 Lumo Lift

The Lumo Lift [7] is a posture correcting wearable which has the same intentions as the wearable that will be designed for this project. Therefore, it is worn to get a feel of haptic feedback and to research the reaction of the body and the mind on this. Experiences, results and conclusions are depicted in this section.

Figure 2.6: Lumo Lift [7]

2.2.1 Research

The Lumo Lift is a small device that measures and corrects the posture of a human body. It is clipped on a tight fitting garment for the upper body, just underneath the collar bone.

An one time installation, pairing and updating of the Lumo Lift with the accompanying smartphone application is executed. A profile for the user is set up where age, weight and length is saved. Furthermore one of the following four option for the usages of the Lumo Lift needs to be selected:

- Help neck pain
- Help back pain
- Help look and feel better
- Other

For this research, the option *other* is selected while the Lumo Lift was worn to research the effect of haptic feedback and the wearing of a wearable, rather than to solve a specific problem such as back pain.

The Lumo Lift is clipped on the upper body garment by placing the device underneath the garment and putting the small magnetic pad on the outside of the garment. Because of the magnetic property of the Lumo Lift, it will stay in place.

To calibrate the device, the user has to stand up tall against the wall and press the Lumo Lift for five seconds until three small buzzes are felt. The device is then calibrated to the correct posture of the user, the user can continue executing her tasks while being measured and corrected on her posture. The correction of an incorrect posture is executed by a vibration, the intensity and threshold of this vibration can be set in the application.

In order to keep track of the user's posture, the application is checked regularly. Here the number of minutes per hour that the user kept the correct posture is shown, settings can be changed and there can be checked whether or not the the user is in the correct position or not, see Figure 2.7(a.).

Whenever it feels like the Lumo Lift has moved, or the user has changed her garment, the device can be re-calibrated by executing the calibration step again.

To gain insights on when haptic feedback on the human posture is desirable, a log is kept, this log can be found in appendix II. In this log the opinion on the Lumo Lift is stated, together with whether or not the feedback was desired during different events.

The smartphone application is checked multiple times, to see whether progress is made and there can also be checked how the position is with respect to the correct posture, see Figure 2.7(b.).

Figure 2.7: (a.) 50 Minutes of correct posture (b.) Deviation from the target position

2.2.2 Results

Lumo Lift its abilities

During the period that the Lumo Lift was worn, it became clear that not every incorrect posture of the body was noticed by the Lumo Lift. Which means that if for example the pelvis and the lumbar spine contained a poor posture, but the thoracic spine contained in a correct posture, the Lumo Lift did not see the whole posture as an incorrect posture. In order to test the abilities of the Lumo Lift to detect (in)correct postures, an experiment is executed where multiple (in)correct postures are executed. The postures are based on knowledge gained by the interview with the physiotherapist, see section 2.1. Several postures are taken-on and there is denoted whether or not the Lumo Lift labels this posture as correct or incorrect. The postures are sketched, see figure 2.8 and 2.9. With the knowledge gained by the literature research, see section 2.3.1, and the interview with the physiotherapist, see section 2.1, there is analyzed whether or not the Lumo Lift labels the postures correctly. In both figures, (a.), (b.) and (c.) are drawn in the left sagittal plane and posture (d.) is drawn in the posterior frontal plane.

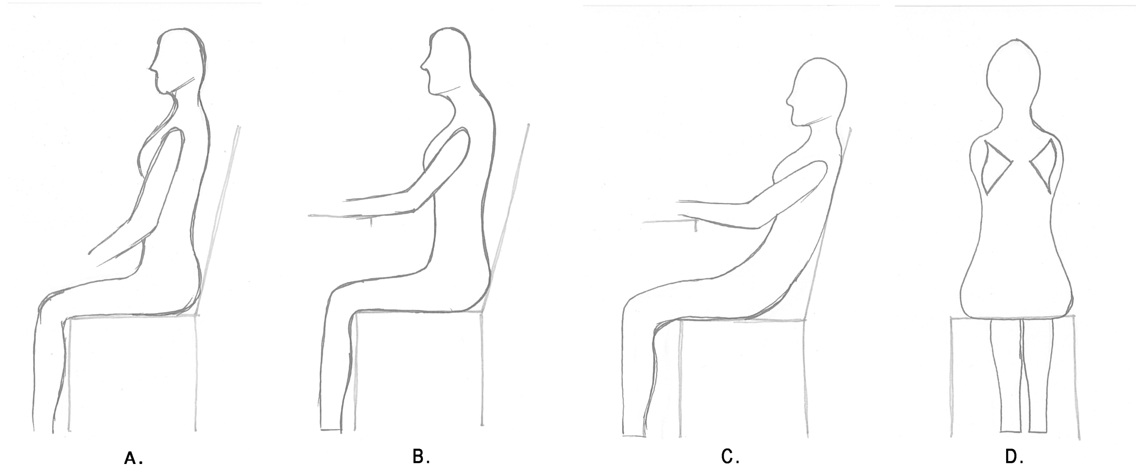


Figure 2.8: Correct postures according to the Lumo Lift

Figure 2.8 depicts the four postures that are labeled by the Lumo Lift as correct postures. However, only posture (a.) is an ergonomically correct posture, (b.), (c.) and (d.) are false positives. Posture (a.) is rightfully labeled as a correct posture, it has a correct neutral pelvis tilt, a correct formed spine and the head balances on top of the spine. Posture (b.) is also correct except for the cervical spine and head, which are too much bended forwards. Posture (c.) is incorrect at the pelvis, it is tilted backwards and is not placed directly underneath the spine, the cervical spine and the head are in correct position. For posture (d.) there was taken-on a correct position, except for the scapulae, they were purposely tilted outwards as explained in section 2.1.1, this was not noticed by the Lumo Lift.

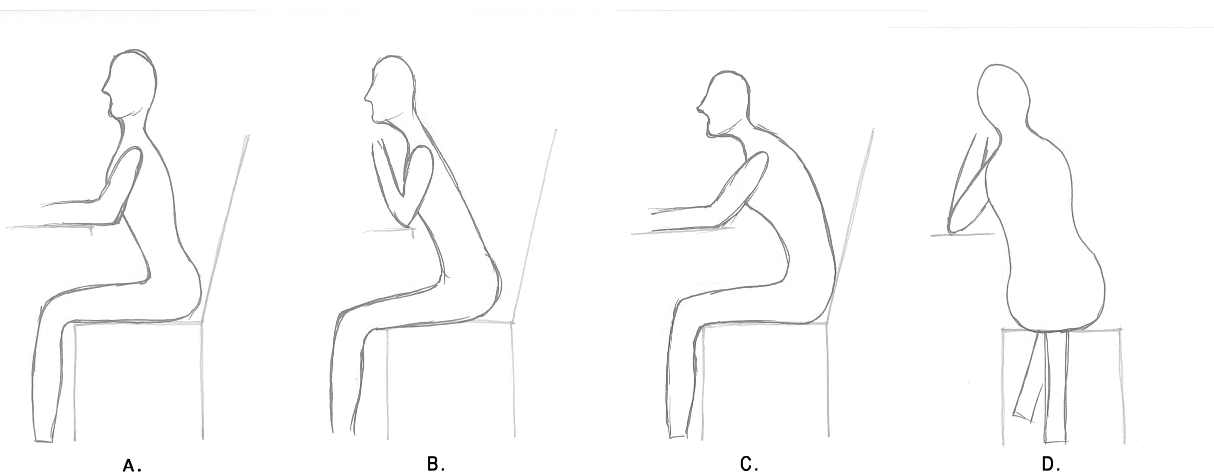


Figure 2.9: Incorrect postures according to the Lumo Lift and researcher

In figure 2.9 the four postures depicted are labeled by the Lumo Lift as incorrect postures.

Posture (a.) has a correct tilted pelvis, but an incorrect spine, because it is bended too much forward, overcompensation of the cervical spine is executed in order to keep the head in a correct position. Posture (b.) has an incorrect pelvis and a straight spine, a lot of pressure is put onto the arms, which holds the weight of the incorrect spine. Posture (c.) is a typical slouching posture, the pelvis and lumbar spine are tilted backwards, the thoracic and cervical spine compensate by bending forwards and the head is tilted in order to look straight forward. At posture (d.), the person leans on his left arm and the legs are crossed, by this the whole body is tiled to the left, which is a poor posture to sit in and thus rightfully labeled as incorrect posture by the Lumo Lift.

Opinion of the researcher & designer

Haptic feedback is something the body has to get used to. At first the Lumo Lift was perceived as very annoying and disturbing. Taking a good posture took a lot of effort and when a small device than says that it is still incorrect, it feels frustrating. However, after some time of getting used to the Lumo Lift, the disturbance of the haptic feedback becomes less. The haptic feedback has however never been perceived as a pleasant feeling and always had a certain amount of disturbance.

After some days there was realized that posture change went more automatically, there was less feedback given by the Lumo Lift. The knowledge that the Lumo Lift is clipped on automatically creates an awareness for the user to mind its posture more. Though, wearing the Lumo Lift for a few days, also learns the user how to avoid the feedback while still attaining an incorrect posture. As long as the upper part of the thoracic spine is in a correct position, the pelvis and lumbar spine can have an incorrect position.

Lastly, there are moment where receiving haptic feedback is just very undesirable. In the application of the Lumo Lift the vibrations can be shut off, but this requires to grab the smartphone, which feels like one step too much. A table of events where haptic feedback is desirable or undesirable is depicted in appendix II.

2.3 State of the Art

Haptic feedback in wearable technology is already researched and executed in the past. In order to get insight into already present knowledge and the projects that are carried out, this section holds information from several papers and projects on haptic feedback, wearable technology, and posture correction.

2.3.1 Literature review

A literature review is composed in order to get insights into how to execute posture correction via haptic feedback. In order to get these insights, four subjects will be addressed. Starting with the different categories of haptic feedback, continuing with how to successfully implement haptic feedback, the third subject is about ergonomically correct postures, and the last subject is on how to execute posture correction for a seated posture. The conclusion on these results will give an estimation of how to combine haptic feedback in wearable technology in order to change people their seated posture.

Different categories of haptic feedback

Haptic feedback can be divided into two categories. The first one is *tactile* feedback. Tactile feedback works on the skin level, so with the use of it, textures and irregularities of the surface can be perceived [[8] as cited in [2]]. There are several types of tactile feedback implementation, but in the scope of haptic feedback in wearable technology, only vibrotactile feedback will be addressed in this literature review. The easiest and most evident way to provide tactile haptic feedback is to make use of vibrations [[9], [10] as cited in [11]]. According to Shull and Damian [12], when using haptic feedback to replace sensory input, continuous vibrational feedback is the least obtrusive and more effective than vibrational feedback with intervals. However, Zheng and Morrell [3] state that when vibrational haptic feedback is used as a coaching element, intermittent feedback is already sufficient. This is while the knowledge of being measured and the possibility of getting feedback creates an awareness by the user which is enough to let the user alter their posture, also without haptic feedback. It is only when there is no feedback for a very long time, that the users start to forget about their posture. The amount of feedback thus depends on the purpose of it.

The second category of haptic feedback is *kinesthetic* feedback, which is also called force feedback. The feedback is given to, and perceived by the muscles [1]. To explain how force feedback works, a robotic surgical tool is taken as an example. Okamura [1] explains that a force feedback device gives feedback to the surgeon by using motors that are programmed in such a way that they recreate the forces sensed by the patient-side robot. Hayward and MacLean [13] add to this that the main idea of force feedback can easily be explained with the use of displacement (d) and the back force (f_e) of an object. When an object is poked, there would be a certain displacement, is it not that the object delivers a certain back force, see figure 2.10. When using a force feedback system, the motors recreate this back force (f_h).

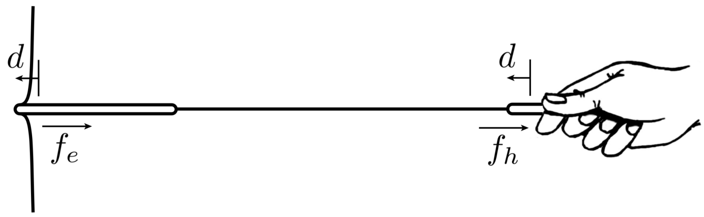


Figure 2.10: Force feedback explained, image by Hayward and MacLean [13]

Bark et. al. [11] state that a vibrational device can also be used to create force feedback. When a vibrational device vibrates with a frequency of 50 kHz or more, the human body does not perceive this as a vibration anymore. It is than felt as a constant force. Neidlinger et. al. [14] developed a 3D printed inflatable device, which was primarily designed to show a person's emotions to the outside world. This was done by the inflating and deflating of the device with air. However, when the inflatables where implemented into garments, a certain pressure was felt when the inflatables became bigger. Which makes this inflatable device also suited for applying kinesthetic force feedback.

Okamura [1] explains that when talking about the interaction with an object both tactile and kinesthetic feedback play a roll. Tactile feedback replicates the information that the skin feels, so it makes the user perceive the texture of the object. Kinesthetic feedback replicates the force that is required from the muscles. So the user perceives the weight of the object while a certain force is required from the muscles in order to lift the object. Minamizawa et. al. [15] add to this that in order to create realistic haptic feedback, both the kinesthetic and the tactile sensation need to be satisfied.

Successful haptic feedback implementation

There are various aspects that influence the desired effect of haptic feedback. The first one is the placement of the haptic feedback on the body. Depending of the situation, the actuators should be placed differently. According to Lindeman [16], when using haptic feedback for a virtual reality implementation, the actuators should be placed on the body where the user is most likely to interact with other objects. Shull and Damian [12] state that when using haptic feedback to guide the human body, vibrotactile actuators should be placed near the body joints. Next to these specific placements, there are also some general placing factors that need to be taking into account. The first one is that according to Lindeman [16], the placement of the actuators should not adversely affect the user. A second factor is that in order to not disturb the user from its tasks, the feedback should be given on a place that is intuitive for the user. This intuitive placement of haptic feedback is obtained by placing vibrational actuators near the spot where motor actions in the body have to be executed, as stated by Zheng and Morrell [3]. Lastly, there has to be taken into account that a vibrotactile sensation has a repulsive instructional cue, which means that the body will move away from the vibration [[17] as cited by [12]].

A second aspect of a successful haptic feedback implementation is, as mentioned before in the paragraph *Different categories of haptic feedback* the amount of haptic feedback. This depends on the purpose of it, sensory replacement or as a coaching element.

A third aspect is the perceived intensity and frequency of the vibration. There is a positive relationship between the vibrotactile stimuli and the suggested mood of an user. High intensity and frequency lead to high levels of arousal, where low intensity and frequency have the exact opposite effect [18]. Dependent on the application and desired effect of the feedback, intensity and frequency should be altered.

Next to all these factors, there is always the fact that new skills take time and regular feedback to be properly developed [3]. Snibe et. al. [19] agree on this and state that a successful effect of haptic feedback is obtained by creating physical intuition for it. Shull and Damian [12] add to this that repetitive task-oriented training of the movement that has to be improved, should be executed.

All these aspects influence the level of success of a haptic feedback implementation. So in order to successfully execute posture correction with the use of haptic feedback, they should all be taken into account.

Ergonomically correct postures

In order to correct someone on its posture, it is important to have the knowledge of what an ergonomically correct posture is. Hulst [20] states that when seated, there are a lot of postures that the human body can take-on, the best one is the neutral posture, see figure 2.11(b.). In this position the force which is required of the muscles is delivered by several muscles along the whole spine, rather than only delivered by the muscles at the cervical part of the spine.

According to Hulst [20] and Falla et. al. [21], attaining a neutral seated posture is done in three steps. Starting with the neutral positioning of the pelvis, which means that pelvis is positioned straight up instead of tilted backwards. The second step is to correct the thoracic and cervical part of the spine, which is achieved by rotating the lower extremities of the

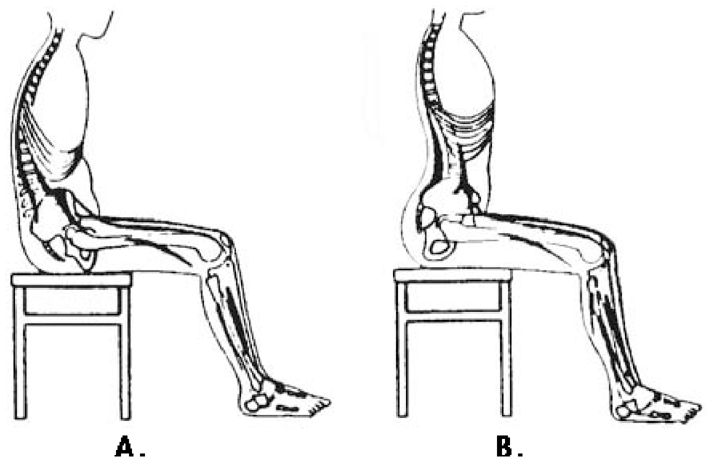


Figure 2.11: (a.) Poor posture (b.) Correct posture, image by Lotte de Vos

shoulder blades slightly inwards. The last step is a sternal lift, which means that the head is placed straight on top of the whole spine.

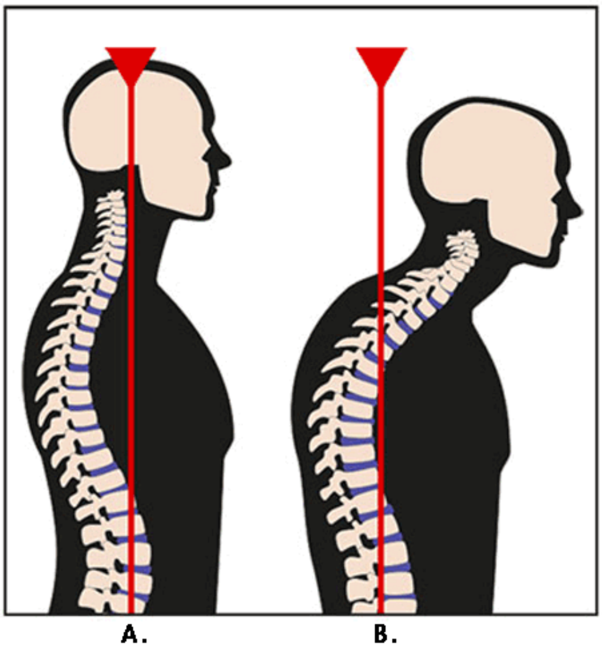


Figure 2.12: (a.) Correct positioning of the head (b.) Forward heading, image by Critical-Bench

From Groenesteijn et. al. [22] their research it has shown that desk work provokes, compared to telephoning, computer work and conversation, the most cervical spine flexion and head inclination. McLean [23] supports this with numbers, the forward heading of people increases with 10% when they execute desk and computer work in comparison to a relaxed seated position. Forward heading is when the cervical spine ante-flexes and the head is not placed on top of the whole spine anymore, see figure 2.12(b.). Falla et. al. [21] state that the deep cervical flexors are the muscles responsible for the placement of the cervical spine and thus also responsible for the correct positioning of the head. Groenesteijn et. al. [22] add to this that it is important to train the deep cervical flexors, when executing a lot of desk work, in order to prevent neck pain. Desk work is a very static task, and that is why it is important to frequently correct to an upright position. Jull et. al. [[24] as cited by [21]] explain that frequently correction to an upright position serves two functions:

1. The cervical spine is alleviated from its initial position which was caused by poor spinal, cervical and scapular postures.

2. The muscles which are necessary for a correct spinal posture are trained.

According to Claus et. al. [25], it is normal for the lumbar spine to have a short lordotic curve. This lordotic curve relies on the position of the hip. This hip position is easier to attain when standing than when sitting, that is why a short lumbar lordosis is more often achieved while standing then when seated.

Posture correction for a seated posture

There are two important aspects for correcting a person's posture. The first one is knowing the person's actual correct posture. Each person is different, so no two persons perfect posture is the same. In order to get to know a person's correct posture, it needs to be measured and captured. This can be done by the use of sensors. The research into which sensors lies out of the scope of this literature review and will be researched separately. To calibrate the user's correct seated posture, the user needs to sit up straight and the result of the sensors is than captured. Outside of the calibration period, a deviation larger than a certain threshold implies an incorrect posture. This threshold needs to be implemented while a slight deviation from the absolute correct posture is still a correct posture. When implementing these sensors into a feedback system, a threshold also needs to be added in time. Because getting out of the correct position does not mean that the user takes on that wrong position, it can also mean that the user reaches out to tie his shoelace and than goes back to his correct position. When the user goes back to his correct posture within the threshold time, there is no need for giving feedback [3] [26].

The second aspect is giving proper feedback on the user's posture. There are several types of feedback that can be given, such as auditory, visual, or haptic. According to Wickens and

Hollands [[4] as cited in [3]], people are able to perform tasks parallel to each other, unless these tasks depend on the same cognitive resources. When executing desk work, the visual cognitive resources are used, so a visual notification on the computer screen would not be the best feedback approach. According to Rao & Aruin and Redd & Bamberg [[27], [28] as cited by [12]], haptic feedback is superior over standard therapy and verbal feedback for lower extremity rehabilitation. This is while the effects of haptic feedback are maintained longer over time. Claus et. al. [25] also add that people cannot attain the short lordosis spinal curve with visual and verbal description alone, facilitation and physical feedback is necessary. Evaluating and combining the theories of Wickens & Hollands [[4] as cited in [3]], Roa & Aruin, Redd & Bamberg [[27], [28] as cited by [12]] and Claus et. al. [25], leads to the assumption that when giving feedback to someone who executes desk work, haptic feedback would be the best choice and the least obtrusive.

Wall et. al. [[29] as cited by [12]] state that the head-tilt angle can be reduced by applying vibrotactile feedback to the sides of the trunk or shoulders. In another research Wall and Weinberg [[17] as cited by [12]] explain that placing arrays of vibrotactile devices around the waist, can help to reduce posterior-anterior trunk tilt of the human body while standing. Whether the vibrotactile feedback is used for head-tilt, trunk tilt or another incorrect posture, Shull and Damian [12] state that vibrotactile actuators should, as mentioned before, be placed near body joints to guide a certain posture.

Zheng and Morrell [3] state that learning of new skills, such as a good posture, requires feedback during the training of it. This feedback should be given at the place where a particular motor action has to be executed. In the case of posture correction, this would be on the muscles that have to work in order to change the posture.

2.3.2 Products and projects

Next to academic literature on haptic feedback for posture correction, there are also products and projects that have haptic feedback implemented to execute posture correction. These are depicted in this section.

Nadi X Yoga track pants

Nadi X [1] is a yoga track pants that has sensors woven into the garment. Actuators at the hip, knee and ankle give gentle vibrations to guide the posture. The power source is a small

[1]https://www.wearablex.com/products/nadi-x-pant?variant=37335539664

Figure 2.13: Nadi X Yoga track pants, by Wearable X

chargeable device called the "pulse", this needs to be attached to the pants behind the left knee. By connecting the yoga pants to the smartphone application, a profile can be created and yoga postures and sessions can be selected.

Lumo Lift

Figure 2.14: Lumo Lift, by Lumo Bodytech

The Lumo Lift [2] is a posture coach and activity tracker. It is a small device that is clipped on the upper body garment, just under collar bone. It measures the correct posture by calibrating and then buzzes when the user slouches. For this project the Lumo Lift is tested, experiences and more information can be found in section 2.2.

Upright GO

Upright GO [3] is a habit forming wearable that tracks and trains the user's posture to create a good back health. It is attached to the upper-back by the use of a hypoallergenic

[2]https://www.lumobodytech.com/lumo-lift/
[3]https://www.uprightpose.com

Figure 2.15: Upright GO, by Upright Tech.

adhesive sticker. If training mode is selected in the smartphone or smartwatch, the device will gently vibrate when the user slouches. Sensitivity and vibration can also be adjusted in the application.

Prana

Figure 2.16: Prana, by Prana Tech

Prana [4] is a clip-on wearable that tracks both breathing and posture and has a positive effect on body and mind. Prana gives a push message on the users smartphone to remind the user on his incorrect posture or irregular breathing pattern. In this way it has physical benefits but also psychological benefits while a regular calm breathing rhythm reduces stress.

[4] http://prana.co

Navigate Jacket

Figure 2.17: Navigate Jacket, by Wearable X Tech

The navigate jacket [5] has no posture implementation, however, it is a good example of haptic feedback implemented into wearable technology. The navigate jacket directs the wearer to his destination by giving directions via LED strips and haptic feedback vibrations. In the accompanying application the user can set his destination and this application sends these directions to the jacket. With the LED strips on the sleeves, the user can see the how far it is until the next turn and how far the journey has already proceeded. The vibrational haptic feedback attends the user on the taking of a turn and more importantly, in which direction. The haptic feedback is implement on the shoulders, so a buzz on the right shoulder means that the user has to take a right turn. In this way the user does not have to look at his phone while walking through the city.

2.4 Conclusion state of the art

In this state of the art several topics are discussed, which together form a good picture of what is already done, and a conclusion can be drawn which supports the continuation of this graduation project.

A poor posture is an accumulation of events, which all starts at the bad positioning of the pelvis. The first step in correcting the seated posture is thus changing the positioning of the pelvis. A muscle that is responsible for the whole posture, and thus also for the positioning of the pelvis, is the Erector Spinae. This muscle lies along the whole spine, so if haptic feedback should be applied to a spot where motor actions should be performed, somewhere on the Erector Spinae would be the right spot.

[5] https://www.wearablex.com/pages/navigate

When using haptic feedback as a coaching element, intermittent feedback is already sufficient while awareness is raised. When intermittent feedback is applied to change the position of the pelvis, there is assumed from the Lumo Lift experience and the outcome of the literature research, that the haptic feedback will create enough awareness that the user will automatically changes the rest of its posture as well. Haptic feedback should thus be given so that the user tilts its pelvis. A proper spot for the placement would be at the lower part of the Erector Spinae, just above the pelvis. This complies with two theories, *"haptic feedback should be given to a spot where motor actions should be executed"* and *"haptic feedback should be given near body joints in order to guide a motion"*.

The Lumo Lift research has shown that one sensor underneath the collarbone is not sufficient enough to map the whole posture of a human body. One sensor can be undermined, so a false positive can be executed. To map the whole upper body's posture, multiple sensors are required. Another experience obtained by using the Lumo Lift, is that there are certain events where haptic feedback is undesirable. There should thus be a possibility to easily shut down the haptic feedback.

The next step

For the graduation project, all these aspects should be taken in account when designing a wearable device that executes seated posture correction via haptic feedback. From all the research, the conclusion is drawn that haptic feedback should be given to the Erector Spinea, just above the pelvis. However, this is theoretically concluded, in order to see whether in reality this is also the correct place, experiments are going to be executed with the placement of haptic feedback actuators at several places on the human body. The Lumo Lift research has shown that one sensor is not sufficient enough for mapping the posture of the human body. To get to know how many sensor are required and where they need to be placed in order to properly map the posture of the human body, experiments are going to be executed which research the amount and the placement of the sensors. Intensity and frequency can make a big difference in the effect of the haptic feedback. High frequencies (50kHz) are perceived as a constant force, and high frequency and intensity lead to high levels of arousal. However, the haptic feedback should not be too disruptive. So also for this topic, experiments will be executed where there will be looked into what frequency is the most suitable to give effective feedback that is not disruptive. When all these questions are answered, the next step will be looking into properly implementing the electronics into the wearable so that it is minimally visible. However, this is not the main focus of the project and will only be done when there is enough time to properly execute this.

This graduation project is novel while the seated posture will be measured by multiple sensors at several places on the human body. The aim is to correct this posture in a non-disruptive manner with the use of haptic feedback in a wearable device, such as a garment for the upper body.

Chapter 3

Methods & Techniques

Several interviews, tests, and experiments are executed in this project to increase knowledge, experiences and insights. In this chapter the methods & techniques that are used for these interviews, tests, and experiments are explained.

3.1 Interviews

The only interview that is executed for this project was to gain knowledge on the topic of posture in the physiotherapy domain, see section 2.1 for the interview with the physiotherapist. There is chosen to execute an semi-structured interview, while the researcher & designer is not familiar in the physiotherapy domain, but does has some ideas which are gained from literature research. The aim of the interview is to gain as much knowledge as possible on the subject of the seated posture. An semi-structured interview is the best form for that, while it gives the opportunity for the researcher to validate her previously gained knowledge, and to increase the knowledge of the subject.

3.2 Experiments

The ideation phase of this project exists out of experiments that are executed in order to get insight in how to properly measure a posture and how to correctly apply haptic feedback. All the experiments follow the small protocol where the goal is stated beforehand, observations & insights are written down during the experiment and afterwards a conclusion is drawn from this. From this conclusion the goal for the next experiment is deduced. The experiments that are supported by data, contain a table where this data is depicted, for the experiments that are supported by experiences, honest opinions and experiences are written down.

3.3 User tests

For this project products and prototypes are tested. While this project has an autoethnographic design method, everything is tested by the researcher & designer. To make sure that this research is done correct, protocols are followed, and logs are kept where honest observations and insights are depicted.

Chapter 4

Ideation

As stated in section 2.4, the next step is the research into the three categories of haptic feedback in wearable technology. These categories are (a.) sensors, (b.) haptic feedback and (c.) wearables. The research into these three categories, and their outcomes are depicted in this chapter. For the complete workbook with all the experiments their goals, observations/insights, and conclusions, see appendix III.

4.1 Postures

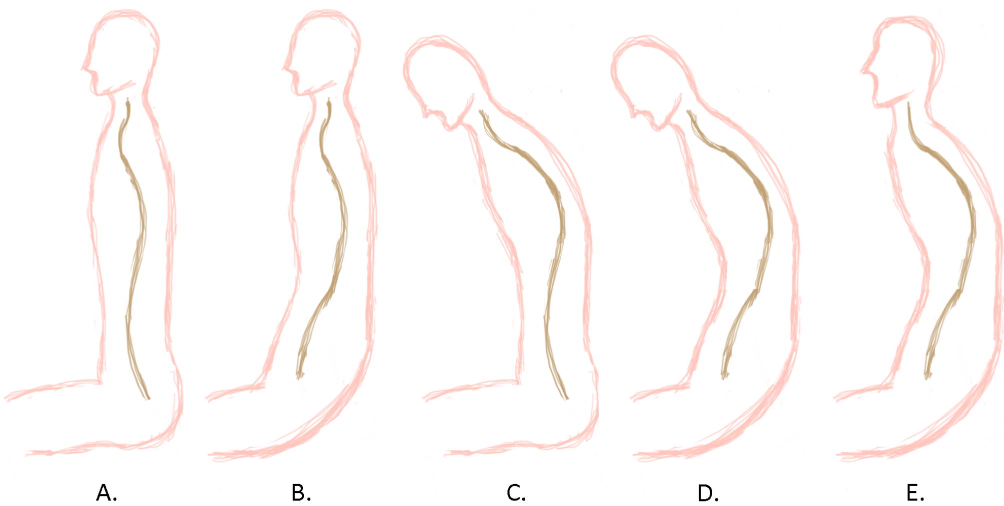


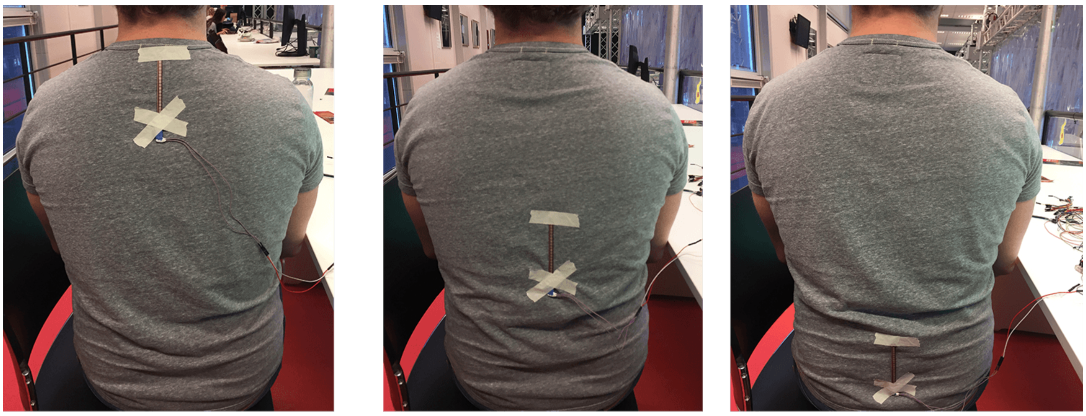
Figure 4.1: Postures (a.) Sitting up straight (b.) Incorrect lumbar spine (c.) Incorrect thoracic spine (d.) Slouching posture (e.) Slouching with head lifted up

On the basis of chapter 2, five postures are used in this ideation phase, these are selected while they are (part of) incorrect postures. They are depicted in figure 4.1, and are the postures (a.) Sitting up straight (b.) Incorrect lumbar spine (c.) Incorrect thoracic spine (d.) Slouching posture (e.) Slouching with head lifted up.

4.2 Sensors

For all sensors that are tested, the five postures of figure 4.1 are taken on by the test person to who the sensors are attached to. By looking at the data outcome, the best sensors, the best placement and the best amount of sensors is defined. These tests are depicted in this section.

4.2.1 Flex sensor



A. B. C.

Figure 4.2: Flex sensor placement (a.) Upper back (b.) Middle back (c.) Lower back

There are two types of sensors tested, flex sensors and accelerometers. Starting with the flex sensor for which three different placement of the sensor are researched. The flex sensor is tested by placing it on the upper, middle and lower back. With each placement of the flex sensor, all five postures of figure 4.1 were taken on and the data was saved. From the experiment several observations and conclusion are derived. The sensor does not give a wide variation of values, so it is not possible to distinguish between the different postures. Furthermore, the whole sensor needs to be very tight to the body. But when the sensor is in a certain position for a long time, it keeps this form. All together makes that the flex sensor unsuitable for the measurement of the posture of the human body while seated.

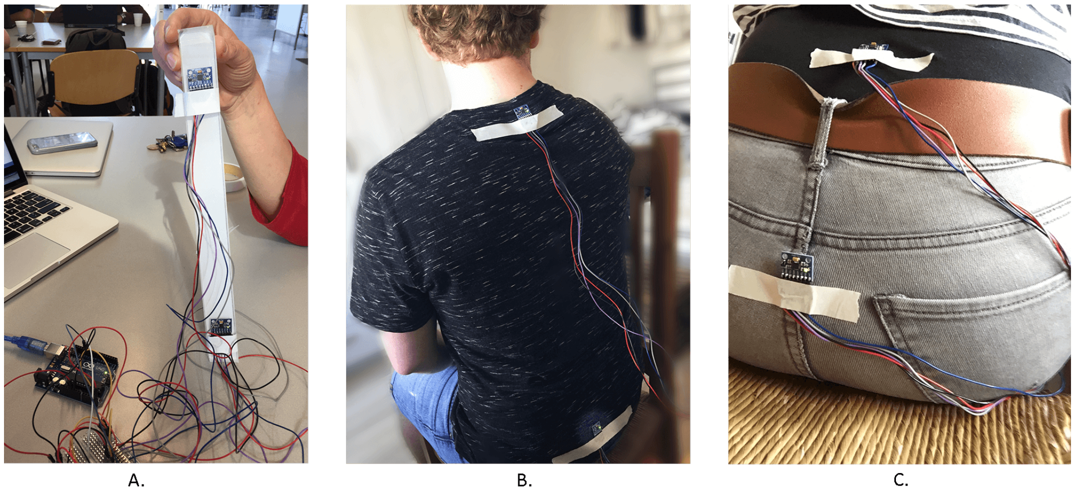


Figure 4.3: (a.) Two accelerometers on a stick (b.) Two accelerometers on the back (c.) Two accelerometers at the pelvis

4.2.2 Accelerometers

With the accelerometers, four experiments are executed. The first one was a simple experiment where two accelerometers were attached to a stick, see figure 4.3(a.). This experiment had as goal to check if the delta result of two accelerometers placed above each other, is 0 (or close to 0). From this experiment it followed that a delta of 0 is never attained and that there should be taken into account that a proper threshold has to be exceeded before haptic feedback should be applied.

Continuing on this stick experiment, a new experiment was executed where one accelerometer was placed on the top of the back, and one on the bottom of the back, see figure 4.3(b.). The test person took on the five postures from figure 4.1, and the data from the sensors was saved. Findings of this experiment were that accelerometers are very easy influenced by movement of, even by of breathing. Next to this inconvenience, there was also something very convenient discovered, namely that from the retrieved data the user's posture could be read. The delta for sitting up straight lies between approximately 2000 and 2100. Thoracic (c.), Slouch(d.) and Slouch with head lifted up (e.) had a delta which started from 3500. This is convenient while when the delta value is above 3500 for the certain amount of time, it implies that the user attains an incorrect posture. However, with this sensor placement, the lumbar incorrect posture, figure 4.1(b.), has a delta between 1700 and 1850, which means that this is not filtered out when there is only given feedback when the delta is above 3500. When also looking at the final implementation of these sensors, they have to be implemented in a wearable. This would means long wires over the whole back and a big wearable surface, this would not be ideal.

The second accelerometer experiment was partly a success, but because of the several inconveniences there was also looked at placing accelerometers at the pelvis, see figure 4.3(c.). An incorrect posture starts at the pelvis, so it also seems logical to read the positioning of the pelvis. The sensors were attached to the user, one just above the pelvis and the other one halfway the pelvis, again all five postures were taken on and the data was saved. The outcome of this experiments was that the delta value of sitting up straight was between 2000 and 2400. But with this placement, all delta values of the incorrect posture lie above the delta of the correct posture. The thoracic nevertheless, already starts at 2400 up to 2900, but from executing the experiments it also resulted that it is very hard to only execute the incorrect thoracic posture, without also having an incorrect lumbar spine, so this does not seem to be a problem. There can be chosen to use a threshold with a delta of approximately 7800.

The last accelerometer experiment is a combination of the placement of accelerometers at the back and the placement of accelerometers at the pelvis. In this experiment three accelerometers are used, one at the top of the back, one just above the pelvis, and one halfway the pelvis. However, the results from this experiment is labeled as unreliable. This is while the experiment is executed two times, but the retrieved data of the separate test did not match with each other. So the placement of three accelerometers is not further researched.

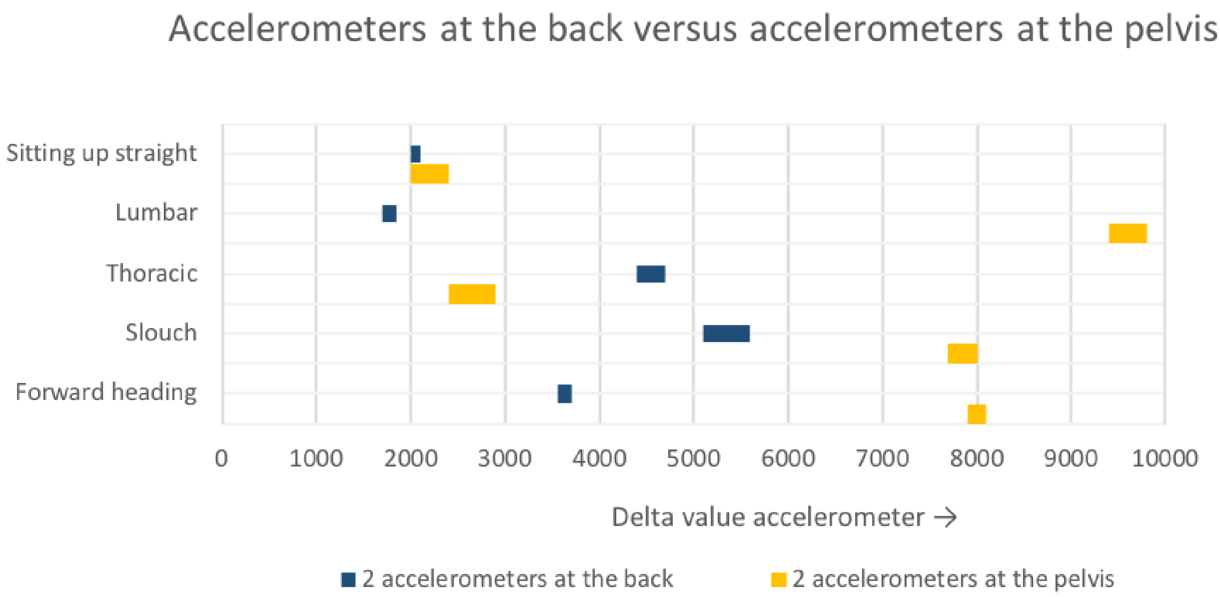


Figure 4.4: Accelerometer placement chart

In figure 4.4 the two successful accelerometer experiments are compared: placing two accelerometers at the back and placing two accelerometers at the pelvis. In the graph, the blue beams represent the delta values of the accelerometer placement at the back. The yellow beams represent the accelerometer placement at the pelvis. There can be seen that the sitting up straight gives a delta value that starts at 2000 for both experiments. Only with the blue beams there is a posture that gives a delta that is less than 2000, the rest of the poor postures of the blue beams start at 3500. And even more practical is that with the yellow beams the poor postures start at 7700, assuming that an incorrect thoracic posture is accompanied by an incorrect lumbar posture. This is convenient while there is a lot of space between the incorrect and correct posture values.

From all the experiments that are executed with the sensors, placing two accelerometers at the pelvis has shown to be most effective for the measurement a posture. The difference in data of the correct and incorrect posture is large, which decreases the problem of the accelerometers being very sensitive. And while the accelerometers are only placed at the pelvis, there is a possibility to make a wearable that only needs to be worn around the waist and at the pelvis. Therefore, this technique will be used in order to measure the posture of the human body while seated.

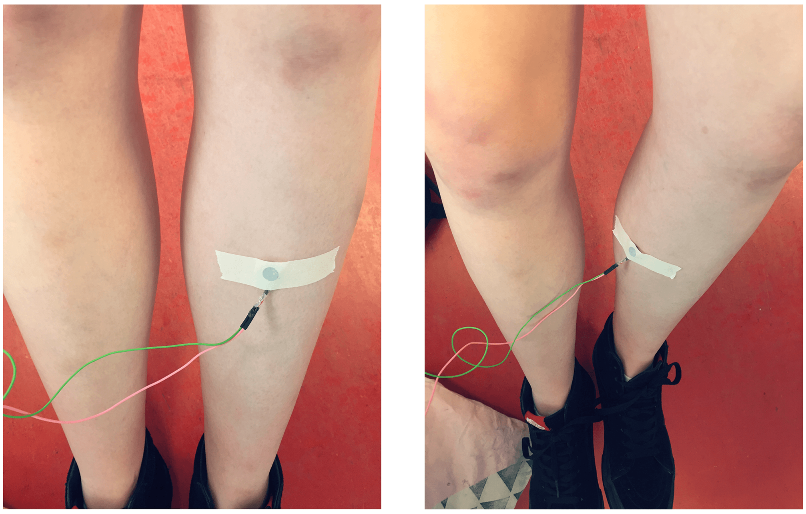
4.3 Haptic feedback

For the haptic feedback part a vibration motor is used as actuator. There are a lot of factors that need to be researched such as the placement of the vibration motor, the material where the vibration motor is placed in, and how many vibration motors there are required. These three categories are depicted in this section.

4.3.1 Placement

The first experiment executed was to research the difference between a vibration motor on the bone and on a muscle, see figure 4.5. This was done by placing a vibration motor on the bone and muscle of the leg, in this case the leg is used while this was easily accessible for the researcher. The outcome of this research has a high value, while there is now, in a very early stage, discovered that vibrations on the bone should be avoided. The vibration on the bone was felt throughout the whole leg and was perceived as highly uncomfortable. A vibration on the muscle is felt less intense, but is still good perceptible, and above all, is perceived as a pleasant feeling.

As a continuation on the placement on bone or muscle, an experiment is executed with



A. B.

Figure 4.5: Vibration motor on (a.) bone and (b.) muscle

the placement of vibration motors on the back of the researcher. Vibration motors are held against different places of the back and the researcher & designer evaluated whether or not these places were perceived as pleasant. The result is depicted in figure 4.6, green indicates the spots where the vibrations were perceived as pleasant and red are the spots that were perceived as unpleasant or even painful. The observations at the unpleasant places are:

- Neck: the vibration goes through the head and the whole spine, creates temporarily headache when the motor is applied.

- Spine: the vibration goes through the whole spine and partly through the pelvis, which feels unpleasant.

- Pelvis: the vibration goes through the whole pelvis and radiates to the upper legs, which is perceived as painful.

- Sacrum: the vibration goes very intense through the whole pelvis, which triggers the need to go to the bathroom.

The green spots on figure 4.6 comply with the previous stated theory that haptic feedback should be applied to the big muscle, just above the pelvis, as stated in section 2.4. The conclusion from these two experiments are that vibrational haptic feedback should be applied just above the pelvis at both sides of the spine.

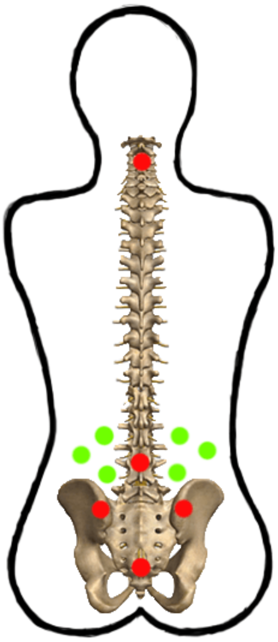


Figure 4.6: Correct (green) and incorrect (red) placement of vibration motors on the back

4.3.2 Vibration dispersing material

The vibration motor itself is a small disk with a diameter of approximately one centimeter. This is only a small surface which can largely be increased when the vibration motor is placed in vibration dispersing material. This is material with a small indentation for the vibration motor. Because the vibration motor is tightly fitted in the material, the material will vibrate along and will thus increase the vibration surface of the motor. To figure out which material is best suited for increasing the surface in the wearable, several materials are researched. These are depicted in the order from least suitable to best option.

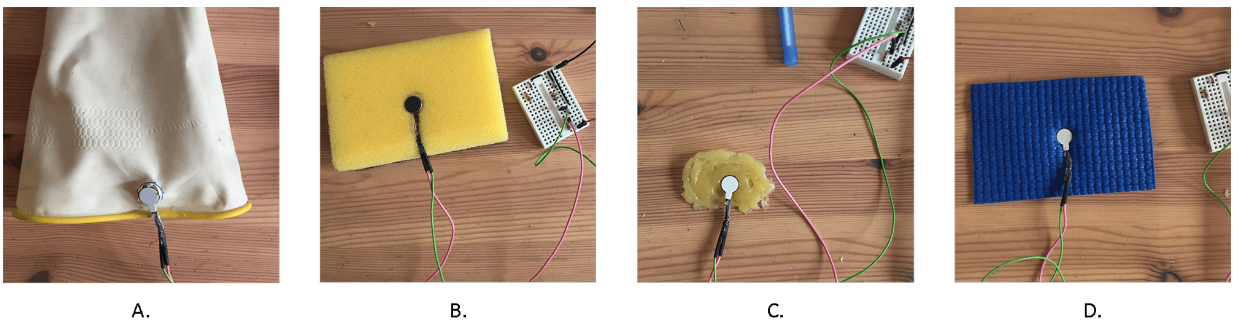


Figure 4.7: Vibration dispersing material with vibration motor (a.) Latex (b.) Sponge (c.) Hot glue gun (d.) Foam

The least suitable VDM (vibration dispersing material) is latex, for this experiment a latex glove is used, see figure 4.7(a.). Latex does increase the effect of the motor, but only when it is held loosely, when the material is on tension it does not radiate the vibrations effectively. The second least suitable material is a sponge, for this experiment a scourer is used, see figure 4.7(b.). It increases the effect of the motor extremely, by which it thus also increase the surface. A plastic object made with a hot glue gun, see figure 4.7(c.), also increases the effect of the motor, even more than the sponge. However, the disadvantage of both these materials are that they are not as flexible as foam. So foam, see figure 4.7(d.), has shown to be a better VDM for in a wearable than sponge or semi-hard plastic, while it increases the intensity and surface and it is also flexible.

Figure 4.8: Vibration dispersing felt

However, the best material to disperse vibrations is felt, see figure 4.8. Felt has all the functions that foam has, but the factor that makes felt better is that it increases the effect of the vibration motor more intense than with foam. Therefore, felt will be used as vibration dispersing material.

4.3.3 Pattern or spot

Before determining the form of the VDM (vibration dispersing felt), there needs to be determined how the vibration motors need to be placed. The first step in this is choosing between vibrational feedback on one spot or on multiple places. This is researched by experimenting with one, two, and three vibration motors attached to the leg, the leg is again chosen because it is easy accessible. For the first experiment one vibration motor is attached to the leg and there is examined what the effect is of vibrational feedback on one spot. For the second experiment two vibration motors are used and there is tested what is perceived when the spot vibration has a bigger surface (two vibration motors cover more surface than one). Next to an increased surface there is also looked at the effect of a pattern, which means that the vibration motors are not on at the same time, but rather take turns with small breaks between them. This experiment is also executed with three vibration motors instead of two. The conclusion from these experiments is that a pattern is preferred over spot vibration. This is while vibrations at one spot feel like someone pokes you, a pattern feels more like a motivational stroke. A pattern can be made with two or more vibration motors, three motors are preferred while these feel more stimulating than two motors.

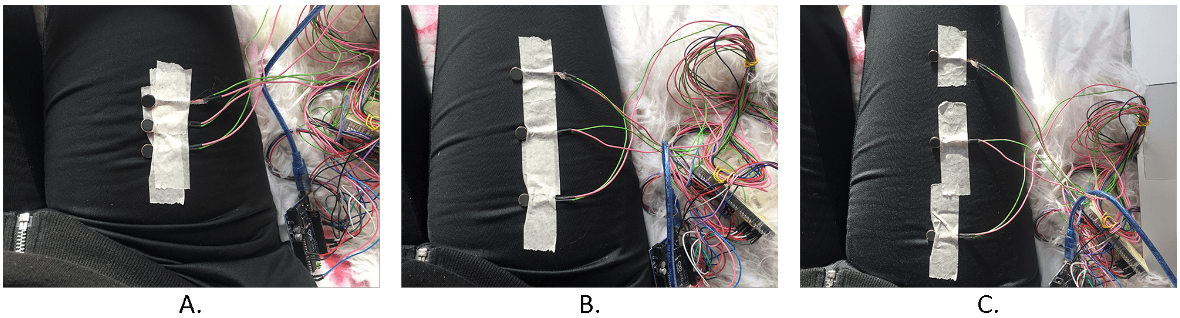


Figure 4.9: Distance between vibration motors (a.) One centimeter, (b.) Five centimeter, (c.) Seven centimeter

For the second wearable, an additional experiment is executed to determine the distance that creates the best perception of a vibrational pattern. This is done by again placing vibrational motors on the leg with a distance between them of one, five & seven centimeter, see figure 4.9. In the first wearable a distance of 3.5 centimeter is used, therefore the gap between one and five centimeter is so big in comparison with the gap between five and seven centimeter. When placing three vibration motors near each other with a distance of only one centimeter, the vibrations do not feel as a pattern but rather as a spot vibration with a large surface. With five and seven centimeter between the vibration motors a pattern is clearly felt. The only difference between five and seven centimeter, is that with seven centimeter there is a lot of distance between the vibration motors and is therefore more disturbing than a distance of five centimeter.

4.3.4 Form vibration dispersing felt

To combine the knowledge about the placement, VDM (vibration dispersing material), and preference for pattern feedback, the next step is designing different shapes for the felt.

In figure 4.10 several sketches are depicted that are considered for VDM. Eventually three designs are chosen and cut out of felt with the use of a laser cutter, see figure 4.11.

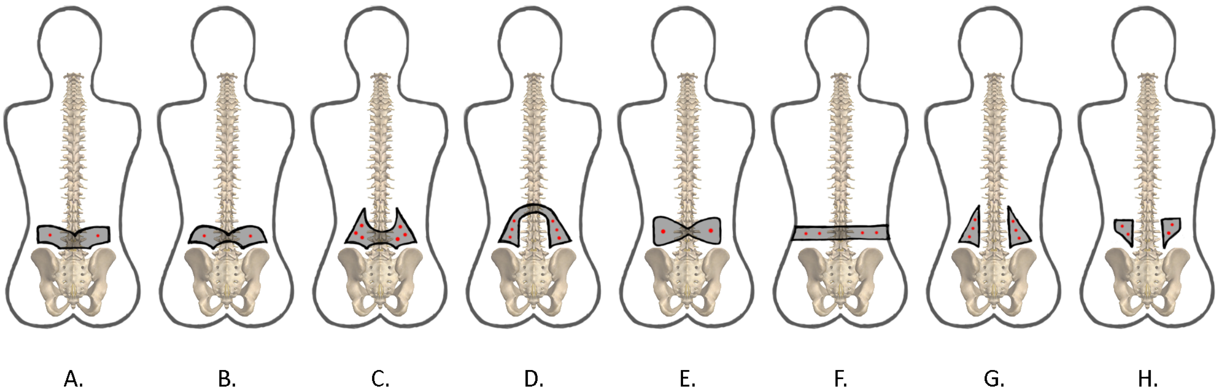


Figure 4.10: Sketches vibration dispersing felt, red dots represent vibration motors

All three the designs depicted in figure 4.11 are tested by the researcher & designer. This is done by putting vibration motors in the holes, and letting someone else press the pieces of felt against the back of the researcher & designer. To see if pattern is still preferred over spot vibration, with all three pieces of felt, spot vibration as well as pattern vibration is applied. The experiments resulted in the observation that the Belt, figure 4.11(a.), is too big to be placed at both sides of the spine, but this could be adjusted in the future. However, this design gives horizontal haptic feedback, which feels very pleasant, but does not motivate to change the posture while it feels more like a massage. The Bridge, figure 4.11(b.), needs to be placed very tight to the body while it is a large surface. Another problem is that the top of this design gives vibrational feedback to the spine, which is perceived as unpleasant. Lastly, the Triangles, figure 4.11(c.), which has as big advantage that they do not touch the spine, the feedback is pleasant and stimulating. However, the points at the side are unnecessary while the vibration is not felt there anymore. A general remark on these designs is that pattern is only felt when there is really concentrated on the feeling of the feedback.

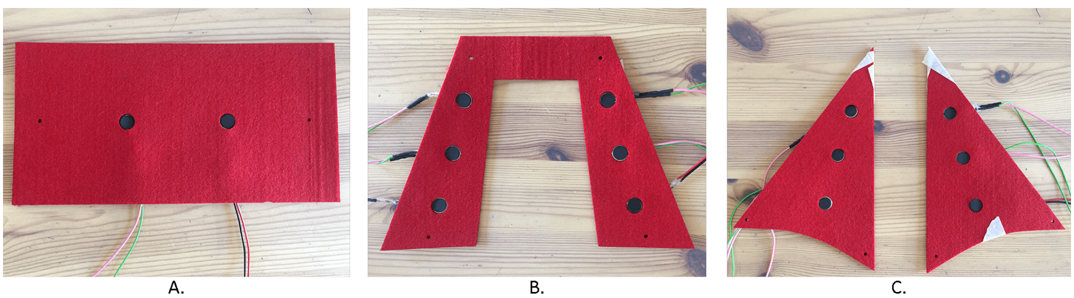


Figure 4.11: Vibration motors in vibration dispersing felt

Chapter 5

Specifications

Conclusions have been drawn from all the experiments that are executed in order to get insight into how to create a posture correcting wearable with the use of haptic feedback. One of these conclusions is that two accelerometers at the pelvis are the best option to measure someone's seated posture. And in order to give haptic feedback to the user that is perceived as pleasant, three vibration motors need to be implemented in felt and should be placed at both sides of the spine where they give an upwards pattern. In this chapter these insights are used to create prototype wearables.

5.1 Requirements wearable

Based on the results from chapter 2 and chapter 4, requirements for the wearable are drawn up. The wearable should:

1. Measure the seated posture accurately
    (a) The pelvis should be covered in such a way that the lower accelerometer has an attachment place.
2. Give appropriate intuitive haptic feedback
    (a) The vibration dispersing material should fit on the back of the wearable
3. Not impede the user
4. Be washable
    (a) The wearable should have as little surface contact with the body as possible

Measure the seated posture accurately means that the wearable should be able to distinguish the user's correct posture from its poor posture. Next to distinguishing the postures, the wearable should also correctly indicate which posture is attained, so that no feedback is applied when a correct posture is attained by the user. Which also partly explains the second requirement, intuitive feedback is required so that the user is as little distracted from her work as possible. Furthermore, should the feedback be applied in such a way that it is not perceived as disruptive or painful. The wearable should not impede the user implies that the wearable should have a high wearability and not obstruct the user in its actions. Because the wearable is worn on the body, possibly with skin contact, it should be washable. This means that or the electronics should be made water tight, or the electronics should be easy removable from the wearable so that only the fabric has to be washed.

5.2 Wearable iterations

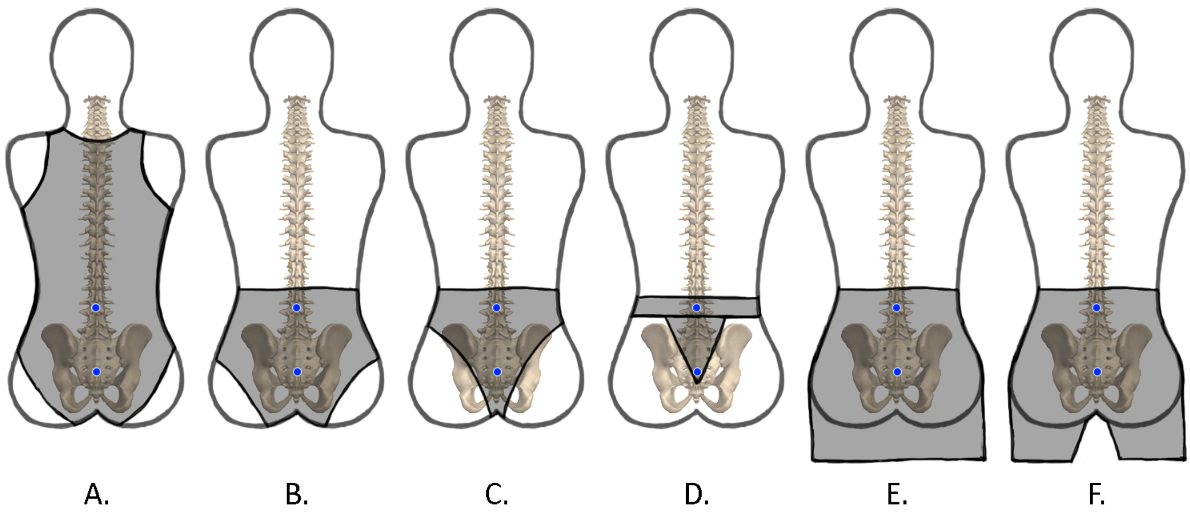


Figure 5.1: Sketches wearables, blue dots represent accelerometers

Before the prototyping starts, a brainstorm with several possible designs for the wearable are made, see figure 5.1. These designs are made on the base of placing the accelerometers, however, they can easily be adapted to satisfy the requirements from section 5.1. The designs are (a.) body, (b.) high waisted panties, (c.) high waisted thong, (d.) belt with "tail", (e.) bodycon skirt, (f.) tight shorts.

5.3 Wearable One

For the first wearable, design D is chosen from figure 5.1. It is inspired by a belt that can be closed at the front side of the body, a tail at the back provides a place where the lower accelerometer can be attached to. This design is chosen while it has the least surface contact with the body, which means that it does not have to be washed as often as for example the panties variant, figure 5.1(b.). Wearable one, see figure 5.2, is mainly created to test if the everything works as is researched. Do two accelerometers at the pelvis really read a posture when they are implemented in a wearable, and is the feedback really as pleasant as there is predicted from the literature and experiments? Because of the rapid prototyping, tucking away the electronics neatly has not a number one priority and is not embedded in the design of wearable one. Table 5.1 depicts the specifications of the electronics used for the measuring of the posture and the appliance of haptic feedback in wearable one. Figure V.1 in appendix V depicts the total setup of all the electronics of wearable one.

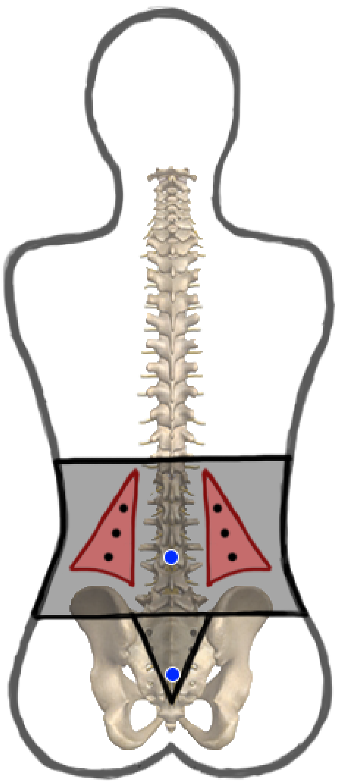


Figure 5.2: Design wearable one, blue spots are accelerometers, red surfaces are the vibration dispersing felt and the grey area is the wearable

	Name	Amount	Dimensions
Microcontroller	Arduino Uno	1x	68.6 mm x 53.3 mm x 10 mm
Sensors	GY521 MPU6050	2x	20 mm x 16 mm x 3 mm
Actuators	Vibrating motor	6x	d: 10 mm h: 2.65 mm
Wire dividers	Breadboard	1x	85 mm x 55 mm x 10 mm
Power source	Powerbank 10000 mAh	1x	60 mm x 91 mm x 22.5 mm

Table 5.1: Electronics specifications wearable one

5.4 Wearable Two

The second wearable is an improvement, based on the testing, of wearable one. The tail was not as convenient as was expected, see chapter 7, therefore, the second wearable is designed on the base of design A from figure 5.1. A body is chosen while the part that goes over the pelvis is not able to shift. Other designs could also have been chosen, but from the research depicted in section 4.3.3, the ideal distance between the vibration motors has been proven to be five centimeter. This covers at least eleven centimeter of the back with vibration dispersing material, so from all the designs of figure 5.1, the body (a.) is the best option.

Wearable two is designed as final product of this project, which means that during the designing process there is taken into account that the electronics should be tucked away neatly, the wires as well as the Arduino and breadboard. So these two elements are embedded in wearable two, and to decrease hight, a breadboard is replaced by a perfboard. See table 5.2 for the specifications of the electronics used in wearable two. Figure V.2 in appendix V depicts the total setup of all the electronics of wearable two.

	Name	Amount	Dimensions
Microcontroller	Arduino Uno	1x	68.6 mm x 53.3 mm x 10 mm
Sensors	GY521 MPU6050	2x	20 mm x 16 mm x 3 mm
Actuators	Vibrating motor	6x	d: 10 mm h: 2.65 mm
Wire dividers	Perfboard	1x	60 mm x 58 mm x 1.5 mm
Power source	Powerbank 10000 mAh	1x	60 mm x 91 mm x 22.5 mm

Table 5.2: Electronics specifications wearable two

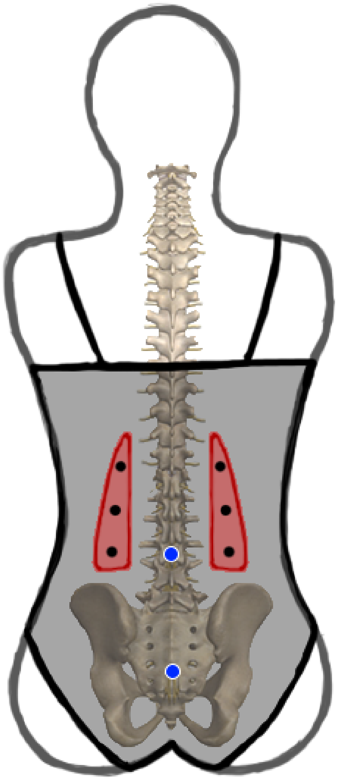


Figure 5.3: Design wearable two, blue spots are accelerometers, red surfaces are the vibration dispersing felt and the grey area is the wearable

5.5 Interaction system

In principle, there are two interactions possible with the system of the wearable, correct posture and poor posture. What these two interactions do to the system, are simplified explained in figure 5.4. See appendix VI for the actual Arduino code and a more elaborated block schema which also explains the steps that the Arduino executes.

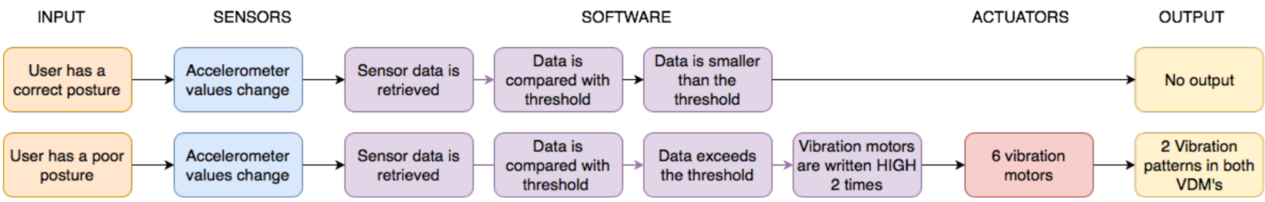


Figure 5.4: Block schema interaction wearables

Chapter 6

Realization

6.1 Wearable One

Figure 6.1: Wearable one

Wearable one is a belt that goes around the lower part of the torso, and has a tail that goes partly over the pelvis. For the material of the belt, tricot fabric is used because of its elastic property. Which is convenient for a wearable that needs to be tight around the body. As a closing mechanism press studs are used. However, the connection of the press studs is stronger than the fabric, which results in the press studs getting out of the fabric, leaving a hole in the fabric. As a replacement, velcro is used as closing mechanism.

As mentioned in section 5.3 is wearable one mainly made to test if all the electronics would work this way. Therefore, the triangle VDM (vibration dispersing material) from the experiment of subsection 4.3.4 is used, even though their design is not optimal, according to the same experiment. The vibration dispersing material is attached to the belt with press studs. Here there is not a problem with the strong connection of the press studs, while they are not as regularly used as the opening and closing mechanism of the belt. Because wearable one is thus only a rapid prototype, the accelerometers are attached to the belt with safety pins, and are the wires not neatly tucked away. All the wires go via a breadboard to an Arduino, which is attached to a powerbank. These three elements can be stored in large trouser pockets or in a small bag which can be carried along.

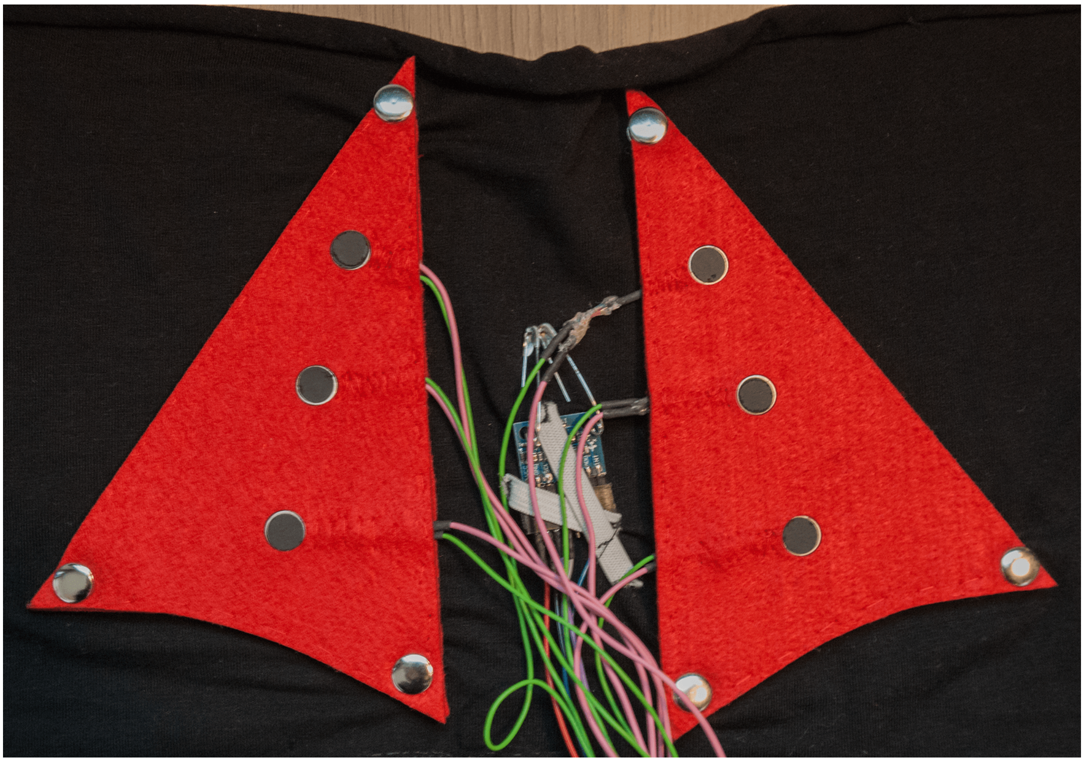


Figure 6.2: Vibration dispersing material wearable one

6.2 Wearable Two

Figure 6.3: Wearable two

Wearable two is a body, which is a singlet and panties in one that has press studs between the legs by which the bottom can be opened. The body is bought at a clothing store, which makes it harder to have an influence on the material. However, the material is 95% cotton and 5% elastane, which is elastic, but more sturdy than the tricot fabric of wearable one.

Wearable two is an improvement on wearable one, which means that it has new VDM (vibration dispersing material), better cable management, and a more neat finish. New VDM is created, for which an additional experiment is executed to determine the ideal distance between the vibration motors, see section 4.3.3. Next to the vibration motor placement, the vibration dispersing felt its form is also adapted, it is smaller, has rounded edges and has more space between the edge and the press studs, see figure 6.4.

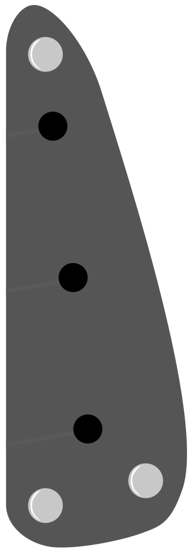


Figure 6.4: Design vibration dispersing material wearable two

Another improvement on wearable one is the attachment of the accelerometers. In wearable one these are attached with safety pins, which is a rapid prototyping solution. However, since wearable two is not meant to be a rapid prototype but rather a proper end product of the project, safety pins are not sufficient anymore. For the accelerometers in wearable two, small covers are designed, see figure 6.5, they contain a press stud by which they can be attached to the wearable. This cover is for attachment to the wearable, but also to make sure the accelerometer is shielded from any sweat, skin contact, or other things that could lead to a short circuit.

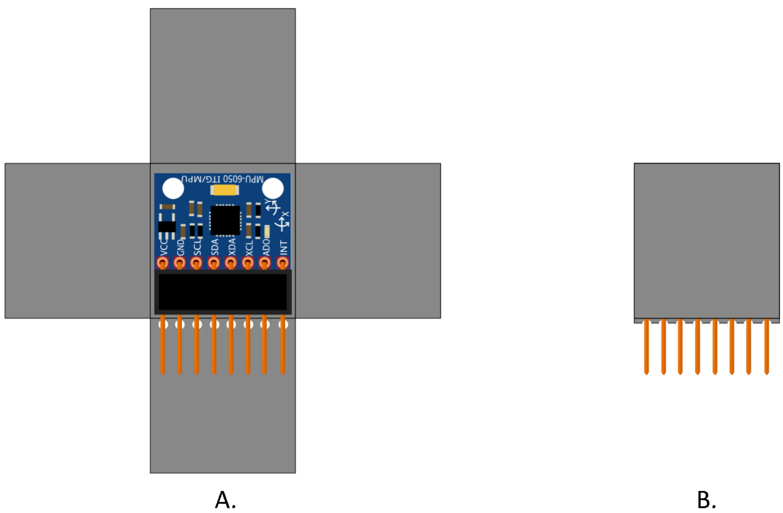


Figure 6.5: Design accelerometer cover (a.) Cover open (b.) Cover closed

For wearable two a better cable management has been executed. This is visible at several spots. All wires are plaited per sensor and actuator, and the solder at the VDM is tucked inside the felt, which enables a neat plaid along the sides of the material. A problem with wearable one was to clumsiness of the bag with breadboard, Arduino and powerbank. In wearable two this problem is fixed, while the breadboard is replaced by a perfboard and is together with the Arduino placed on the wearable, see figure 6.6. In this way only the powerbank is external from the wearable.

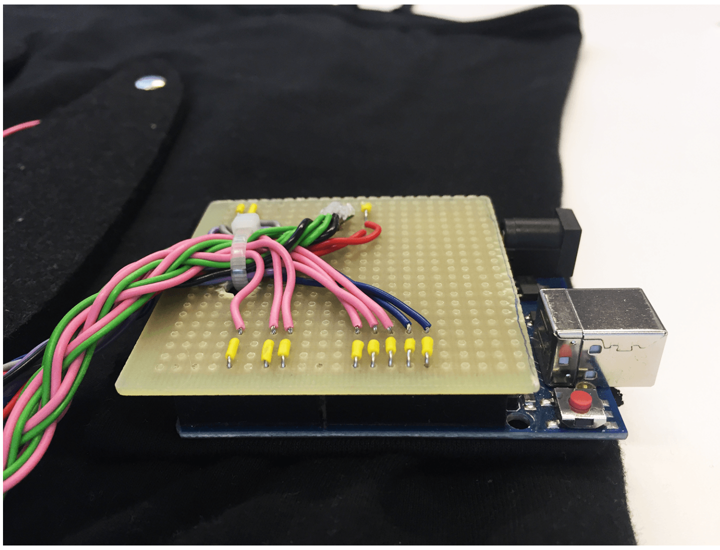


Figure 6.6: Perfboard & Arduino wearable two

There is chosen to put all the electronics and vibration dispersing material at the outside of the wearable. This might not look the most neatly tucked away, but from the testing of wearable one there was concluded that the felts and electronics should not touch the skin. Since this wearable is still meant to be worn below the clothing, there is chosen for functionality over aesthetics.

Chapter 7

Evaluation

To evaluate whether or not the wearables really function, an evaluation phase is done with each wearable. This means that the wearable is worn by the researcher & designer and it is tested according to a protocol, next to the protocol there is also a log kept which both can be found in the appendix IV.

7.1 Wearable One

Wearable one is worn only shortly to test if the system works according to the expectations. The test period was 22 June 2018 through 24 June 2018.

7.1.1 Log summary

The vibrations are perceived as pleasant. But every time feedback is given, the pattern is applied three times, which might be a bit too much. There is tested with wearing the wearable over a singlet and underneath a singlet. When it was underneath a singlet, the wires and vibration dispersing felt touched the skin, which was not as pleasant as expected from the felt, it felt sweaty and the wires were uncomfortably sticky on the skin. Another problem with placing the wearable straight on the skin, was the contact between the accelerometer and the skin, this sometimes made a short circuit by which the whole program automatically stopped. It is very annoying that it is not possible to see whether the system really works without getting the whole Arduino out of the bag, which takes a lot of effort since there is not a proper cable management. This poor cable management also lead to wires popping out of the Arduino and breadboard, which is inconvenient and also annoying. All the cables together make the external electronics part of the wearable very big, and it decreases the wearability drastically. All the wires are not only inconvenient, they are also perceived as socially awkward, while a lot of wires go from underneath a shirt to a bag that is carried around, it feels as if there is something wrong with you. Another socially awkward situation is when haptic feedback is received in a very silent environment, the vibrations are then clearly audible.

The accelerometers can clearly measure posture, which is very good. However, the tail is not as convenient as hoped. There is no feedback when the wearer stands up, but standing up makes the sensor at the tail move. When this lower sensor is moved only a bit, it already gives wrong data, which has multiple times lead to constant feedback while a proper posture was attained. Next to the inaccuracy of the sensor on the tail, another problem with the tail is that it is a lot of fabric that is not tight and thus feels uncomfortable in the trousers.

7.1.2 Requirements satisfaction

In section 5.1 several requirements for the wearable are drawn up. After testing wearable one, this section will briefly depict a small reflection of the wearable with regard to the requirements.

Measure the seated posture accurately

The wearable should, according to requirement one, accurately measure the seated posture. Wearable one partly satisfies this requirement, it did measure the seated posture accurately, but not all the time. When the tail shifted, the sensors and Arduino together, were not able to measure the posture correctly.

Give appropriate intuitive haptic feedback

Haptic feedback should be appropriate and intuitive, according to the testing experiences did wearable one satisfy this requirement. The only remark was that the amount of haptic feedback patterns might be a bit overdone, but this could be adapted.

No impedance of the user

Impeding the user was something that wearable one definitely did. It was bulky, the wires were inconvenient and the user was genuinely obstructed in her actions. This was expected on beforehand, but could partly have been prevented by a better cable management.

Washable

Wearable one is washable, all the electronics are attached with press studs or is already external, so the fabric of the wearable can easily be washed.

7.1.3 Enhancements

During the testing of wearable one, several enhancement for future prototypes were thought of. These enhancements and the enhancements that were came up with while analyzing the logs, are depicted in this section. They can be applied in the designing of wearable two.

- Less vibrational patterns per time that haptic feedback is applied
- Better cable management:
  - Unable wires to pop out of the breadboard and Arduino
  - Tuck away the cables so that they do not come from underneath the upper body garment
  - Weave the wires along the sides of the vibration dispersing felt
  - Make it possible for the wearer to see if the wearable is still working.
- Felt and wires should not be applied on the skin
- Isolate the accelerometers so that no short circuit can be made and so that they can be properly attached to the wearable
- Change the design of the wearable so that the tail part cannot move and does not feel as bulky in the trousers.
- Decrease the noise of the vibration motors

7.2 Wearable Two

Wearable two is worn for a longer period of time to properly test if the system works accordingly, but also if it really has an effect on the user's posture. The test period was 27 June 2018 through 1 July 2018.

7.2.1 Log summary

During the testing of wearable two, it became clear that the threshold was not correct. Only very poor slouching postures were recognized, while slight slouch postures that should be corrected, did not lead to the appliance of haptic feedback. Therefore, the threshold was adapted and two more days of testing were executed with a better threshold. This was successful and all slouch postures were corrected. The wearable genuinely keeps measuring the posture correctly throughout the day, so no re-calibration is necessary.

Wearable two is generally perceived as way more comfortable than wearable one, which results in forgetting that the wearable is even worn. The only two elements that remind the user on the fact that she is wearing the wearable, are the Arduino and the battery. The Arduino its positioning is a bit unfortunate, while it points in the back of the user, when seated against the back rest of a chair, and it is exactly at the height of the waistband of a high waisted jeans. The wearable stays properly in place, even after standing up walking and being seated again, it still gives feedback at the correct time and in a proper way. When standing up straight the wearable is however a bit tight in the crotch. And when the lower part of the wearable is not positioned correctly, the lower accelerometer sometimes sticks in the buttock, but that is fixable by slightly shifting the lower part of the wearable. The wearable is quite hot to wear on warm days.

The vibration dispersing felt is not pressed very tight against the back, so when sitting up straight, feedback is not really perceived. This also results in not really perceiving the third vibrational pattern when feedback is applied. Therefore, after two days of testing, the amount of feedback patterns is scaled back to only two, which was perceived as way more pleasant. The first pattern reminds the user of her posture, and the second support the movement to a correct posture. The feedback is perceived as slightly disruptive when there is totally forgotten about the wearable, but not so disruptive that the user is completely distracted from her work.

A general remark is that it is hard to constantly attain a correct posture and work all day behind a laptop, it is perceived as tiring. Which results in poor postures at the end of the workday/in the evening. When tired, the feedback easily annoys the user, which is exhausting at the end of the day.

An element of the wearable that should be altered is the powerbank/battery, it has to be smaller. Currently, a powerbank of 10000 mAh is used which is, after all the testing of both wearable one and two, still half full. When taking a battery with less capacity, for example 5000 mAh, its size will also be smaller. And when the battery itself is smaller, it can be implemented in the wearable so that there is no electronic element external from the wearable anymore, which would be optimal.

7.2.2 Requirements satisfaction

In section 5.1 several requirements for the wearable are drawn up. After testing wearable two, this section will briefly depict a small reflection of the wearable with regard to the requirements.

Measure the seated posture accurately

Wearable two measures, after the adaption of the threshold, accurately the seated posture of the user. Sensors do not move during the usage of the wearable, so the users posture is measured correctly throughout the whole day.

Give appropriate intuitive haptic feedback

The haptic feedback is perceived as pleasant and not painful. However does feels like a surprise after forgetting that the wearable is worn. Adjustments could be made so that the feedback is perceived more intuitively.

No impedance of the user

The wearable almost did not impede the user. The only thing that is a bit inconvenient is the Arduino at the back of the wearable which is clearly felt when sitting against the backrest of a chair.

Washable

Wearable two is washable, all the electronics are attached with press studs, so the fabric of the wearable can easily be washed.

7.2.3 Enhancements

During the testing of wearable two, several enhancement for future prototypes were thought of. These enhancements and the enhancements that were came up with while analyzing the logs, are depicted in this section. They can be applied in the designing of future prototypes.

- Decrease the size of the accelerometers or at least make sure they cannot point in the skin of the user. This can be done by rounding off the corners or putting the accelerometers in silicone
- Use another microcontroller, a smaller one without headers will decrease the size of the microcontroller-perfboard unit
- Put the microcontroller higher on the wearable and at the front side instead of the back (test the height with the use of highwaisted jeans)
- Make an option in the system that threshold can easily be adapted (for the weariness at the end of the day)
- Plait the wires inside the vibration dispersing material instead on the outside
- Solder together the ground wires of the three vibration motors per VDM, in this way only one ground wire has to go from each VDM to the Arduino (less wires in wearable)
- Make use of a smaller battery so that it can also be implemented *in* the wearable
- When using a body again, use one with a longer back so that it is not tight in the crotch
- Try making a wearable that has less skin surface contact
- Make the intensity of the vibration motors in the first pattern less intense than the second, so that the haptic feedback is perceived as more intuitive

Chapter 8

Discussion

This project is executed according to an autoethnograhpic design method. From auteothnographic research there is always a certain amount of generalizability, which means conclusion would not only apply to the user, but also to other people. A review of the generalizable parts of this project are stated in this chapter, accompanied by a reflection on the applied autoethnographic design method.

8.1 Generalizable

In order to create a wearable that applies haptic feedback according to a measured posture, it is essential to have the knowledge about how to measure this posture. Therefore, extensive research is executed into measuring posture, this is done with regard to the kind of sensors, the amount of sensors, and their placements. These experiments are supported by their raw data, and are therefore generalizable. This means that the outcome of these experiments will apply to more people than just the researcher & designer.

The haptic feedback part of the research is harder to generalize, while these experiments are not based on raw data, but rather based on opinion. However, in experiment III.3.1 research is done into the difference between a vibration motor on bone or on muscle. This resulted in the clear conclusion that a vibration motor on a bone is perceived as unpleasant. Experiment III.3.4 supported this conclusion, while in that experiment, placing vibration motors on bones created an unpleasant feeling, and where vibration motors on some bones even provoked pain. With the knowledge of these two experiments, it will be highly likely that placing a vibration motor on a bone is also unpleasant with other people. So with a certain amount of certainty there is stated that the the result of these two experiments is generalizable.

Another haptic feedback experiment that can be generalized is experiment III.3.7, where the influence of distance on the perception of vibrational feedback patterns is researched. The results from that experiment are so opinion-less that they are almost fact. There is only stated what is perceived and not which further feeling is attached to it. Therefore, with a certain amount of certainty, there can be stated that experiment III.3.7 is generalizable.

8.2 Refection on the applied autoethnograhpic design method

This project is executed with the use of an autoethnographic design method, which means that everything is based on the researcher & designer. This is with regard to her body, but also opinion and taste. A reflection report is written which treats, amongst others, the effect of the autoethnograhpic design method on this project. The full version is stated in appendix VII, this section depicts a small recapitulation where also the last phases of the project are taken into account.

8.2.1 Bias

The challenge of participant observation in autoethnographic research lies, according to Duncan [5], in mastering of the art of self reflection. For this project several interviews, experiments, and user tests are executed. In ethnographic research, these all have to be executed as objective as possible. But since this project is an autoethnography research, a certain amount of bias is required in order to attain the goal.

For this project, one interview is executed with the physiotherapist. This interview was to get insight in an, for the researcher & designer, unfamiliar domain. Therefore, a semi-structured interview approach is used to retrieve as much knowledge as possible. In this section of research, bias is not really in the picture. Especially because this interview was more a lecture on everything there needs to be known about the posture of the human body.

With the knowledge of the interview, and the rest of the state of the art, experiments are executed to whether or not the theory could be verified. Half of these experiments executed are supported by raw data and are therefore hard to label as biased. The other half of the experiments are supported by the opinion of the researcher & designer and are therefore biased. However, for this project an autoethnographic design method is pursued in order to achieve the goal of the project, which is making a wearable that corrects the researcher & designer her posture. So with this reasoning, there could be stated that this way of researching requires bias, while it is the only way to create a wearable that accomplishes the goal of this project.

The user tests are clearly documented and protocols are drawn up in order to make the testing re-executable. According to Yin [[30] as cited by [5]], autoethnographic research its reliability will increase when a protocol is followed that allows other people to execute the same research. These protocols are executed, and logs are kept where honest remarks, insights and opinions are depicted. Which makes the testing subjective, but it is important to have a proper balance between objectivity and subjectivity. And since the researcher & designer strives to create an academically correct project, a proper balance is attained.

8.2.2 Skills

For this project a posture correcting wearable with haptic feedback implemented is developed. This big project can be divided into three main categories: (a.) posture, (b.) wearable technology, and (c.) haptic feedback. The researcher her professional field of expertise lies mainly in the haptic feedback category. Wearable technology is a combination of electronics and clothing design, from which only the technology part lies withing the researcher her field of expertise. And finally the posture category, this lies in the physiotherapy domain, which does not corresponds with the field of expertise of the researcher. Half of the domains do not lie within the field of the researcher's expertise, which makes it questionable whether or not the researcher is skilled enough to create a wearable that has haptic feedback implemented to properly corrects someone on its posture.

However, there are theories that state that a certain amount of unfamiliarity of the research topic is necessary for good autoethnographic research [[31] as cited in [32]]. Burdell and Swadener [[33] as cited in [32]] also state that unfamiliarity in the research topic leads to a topic of conversation, which often provide extra unexpected information. For the first research stage, the State of the Art, a physiotherapist is interviewed. From this interview, the knowledge of a correct posture and how to attain this, is gained. Based on this interview and some academic literature, the posture category of the project is executed. In order to check if the gained information is properly embedded, the professional opinion of the physiotherapist on the prototype can be asked. As with the physiotherapist, multiple other specialists could be asked to give their professional opinion on the prototype, in order to find out whether or not the unfamiliar domains are correctly executed.

Chapter 9

Conclusion

In order to get an answer on the research question "How to design haptic feedback in a posture correction wearable from an autoethnographic perspective?", research is executed in several of domains. From interviewing the physiotherapist, the most valuable posture knowledge is gained with which subquestions 2: "What is a poor posture?" and 3: "What constructs a good posture?" can be answered. A poor posture starts with a change of pelvis positioning, which means that the pelvis is tilted backwards. Because the lower part of the spine is statically connected to the pelvis, it also moves backwards, which leads to a shift in center of gravity of the body. To prevent the body from falling backwards, the upper part of the spine compensate by tilting forwards. A result of this compensation is that the shoulder blades turn more sidewards, rather than staying at the rear side of the back. Another result from the new positioning of the upper part of the spine, is that the head nods downwards. In order to properly look forwards, the chin is extended, by which the head is tilted. This accumulations of events create a poor posture of the human body while seated. In order to fix this poor posture, it is important that the pelvis is positioned correctly. This already corrects the lower part of the spine. The upper part of the spine can be corrected by placing the shoulder blades at the rear side of the back again. Lastly, the vertebrae of the neck need to be placed straight above each other by which the head can balance on top of the whole spine.

There are two types of haptic feedback, *tactile haptic feedback* and *kinesthetic haptic feedback*. For this project tactile feedback is used, while kinesthetic feedback requires large equipments for its appliance, which makes it unsuitable for wearable technology. A Lumo Lift test has confirmed the hypothesis that in order to apply non disruptive haptic feedback, intuitive placement of the actuators is required. In case of changing posture, this placement is near body joints that guide the movement, and on the muscle that has to be activated in order to change the posture. So in order to adjust the seated posture, haptic feedback should be applied to the big muscles at the back, just above the pelvis. Haptic feedback can be applied as spot vibration or as pattern vibration. In order to recreate a motivational push, pattern vibration should be used with a distance of five centimeter between each of the three vibration motors. Each time that haptic feedback is applied, two of these patterns should be executed, where the first on is mainly a reminder of the poor posture, and the second one provides a support for changing the posture.

There are several ways to measure posture, but placing two accelerometers at the pelvis has shown to be the most effective in the measurement of the typical slouching posture. When implementing two accelerometers in a wearable, one should be placed at the top of the pelvis and the other one approximately halfway the pelvis. These placements enable the measurement of the pelvis tilt, which is most effective to measure, while that is the first step in attaining a poor posture.

So, to answer the question "How to design haptic feedback in a posture correction wearable from an autoethnographic perspective?", start with gaining knowledge in the domains of haptic feedback, postures and wearable technology. Use this knowledge to execute experiments that define the placement of sensors and actuators. Implement these placements in a prototype wearable. Test and evaluate this prototype and list recommendations for the next wearable. Finally, it is important to not forget to keep the focus at the research & designer throughout the whole process, while a posture correcting wearable is created in order to fix *her* posture.

Chapter 10

Future work

Chapter 9 depicts a solid conclusion based on the research of this project. But because there is always room for improvements, will this chapter depict suggestions for future research.

Because the wearables of this project contain several sensor and actuators, a lot of wires are present. They lie at the outside of the fabric, but with future research there could be looked into implementing these wires in or through the fabric. Than only the sensors and actuators themselves need to be disconnected when the wearable needs to be washed. Electronics and water do not work together, that is why the electronics should be disconnected before the wearable is washed. However, when the electronics would be made watertight, this might not be necessary anymore. So another suggestion for future research is finding a way to make electronics watertight.

A different option is to create a wearable that is not embedded in fabrics, by which the washing of the fabric problem is dismissed. The focus of the wearable would then lie on the crucial elements that are required for the measuring of posture and the appliance of haptic feedback. These elements could be embedded in silicons to make a girdle which can be cleaned with a damp cloth. The micro controller could than be embedded in the band around the waist, see figure 10.1. In future prototypes or researches there should be made use of smaller microcontrollers than the Arduino Uno.

When a microcontroller would be used that is able to send data via bluetooth, an addition to the wearable could be an application for the smartphone. This application could show the user's progress, or enable the user to setup its preference for threshold. Another element that should be made smaller, or at least less pointy, is the accelerometer. And since only five out of the eight ports are used, there might be a possibility to decrease its size, by creating a sensor that only stores the elements required for the measurement of posture.

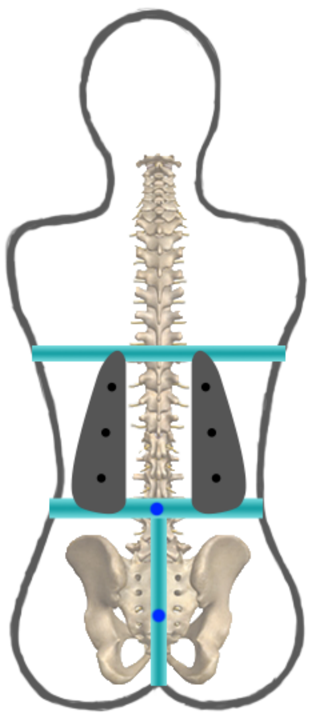


Figure 10.1: Girdle design with only the crucial posture measuring & haptic feedback applying elements

Bibliography

[1] A. M. Okamura, "Haptic feedback in robot-assisted minimally invasive surgery," *Curr Opin Urol*, vol. 1, no. 19, pp. 102–107, 2009.

[2] M. A. Eid and A. O. Osman, "Affective haptics: Current research and future directions," *IEEE Acces*, vol. 1, no. 4, pp. 1–16, 2015.

[3] Y. Zheng and J. B. Morrell, "A vibrotactile feedback approach to posture guidance," *IEEE Haptics Symposium 2010*, vol. 1, pp. 351–358, 2010.

[4] C. Wickens and J. Hollands, *Engineering Psychology and Human Performance.* Harper Collins, 1992.

[5] M. Duncan, "Autoethnography: Critical appreciation of an emerging art," *International Journal of Qualitative Methods*, vol. 4, no. 3, 2004.

[6] C. Russel, "Autoethnography: Journey of the self," 1999. [Online]. Available: http://www.haussite.net/haus.0/SCRIPT/txt2001/01/russel.html

[7] "Web site of the Lumo Lift - Posture Coach and Activity Tracker." [Online]. Available: https://www.lumobodytech.com/lumo-lift/

[8] M. Eid, M. Orozco, and A. El Saddik, "A guided tour in haptic audio visual environment and applications," *Int. J. of Advanced Media and Communication*, vol. 10, no. 1, pp. 10–17, 2007.

[9] A. Bloomfield and N. I. Badles, "Virtual training via vibrotactile arrays," *Presence: Teleoperators and Virtual Environments*, vol. 17, no. 2, pp. 103–120, 2008.

[10] L. A. Jones, B. Lockyer, and E. Piateski, "Tactile display and vibrotactile pattern recognition on the torso," *Advanced Robotics*, vol. 20, no. 12, pp. 1359–1374, 2006.

[11] K. Bark, J. Wheeler, G. Lee, J. Savall, and M. Cutkosky, "A wearable skin stretch device for haptic feedback," pp. 464–469, 2009.

[12] P. B. Shull and D. D. Damian, "Haptic wearables as sensory replacement, sensory augmentation and trainer - a review," *Journal of NeuroEngineering and Rehabilitation*, vol. 12, no. 1, 2015.

[13] V. Hayward and K. MacLean, "Do it yourself haptics: Part I," vol. 14, pp. 88 – 104, 2008.

[14] K. Neidlinger, K. Truong, C. Telfair, L. Feijs, E. Dertien, and V. Evers, "AWElectric: That gave me goosebumps, did you feel it too?" *TEI '17*, pp. 315–324, 2017.

[15] K. Minamizawa, D. Prattichizzo, and S. Tachi, "Simplified design of haptic display by extending one-point kinesthetic feedback to multipoint tactile feedback," *2010 IEEE Haptics Symposium*, pp. 257–260, 2010. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5444646&isnumber=5444605

[16] R. Lindeman, R. Page, Y. Yanagida, and J. Sibert, "Towards full-body haptic feedback: The design and deployment of a spatialized vibrotactile feedback system," *VRST'04*, pp. 146–149, 2004.

[17] C. Wall and M. S. Weinberg, "Balance prostheses for postural control," *IEEE Eng Med Biol Mag*, vol. 22, pp. 84–90, 2003.

[18] A. Mazzoni and N. Bryan-Kinns, "Mood glove: A haptic wearable prototype system to enhance mood music in film," *Entertainment Computing*, vol. 17, no. 17, pp. 9–17, 2016. [Online]. Available: https://doi.org/10.1016/j.entcom.2016.06.002.

[19] S. S. Snibbe, K. E. Maclean, R. Shaw, J. Roderick, W. L. Verplank, and M. Scheeff, "Haptic techniques for media control," *UIST '01*, pp. 199–208, 2001.

[20] "Personal communication with physiotherapist Christine Hulst, 10 March 2018."

[21] D. Falla, S. O'Leary, A. Fagan, and G. Jull, "Recruitment of the deep cervical flexor muscles during a postural-correction exercise performed in sitting," *Manual Therapy*, vol. 12, no. 2, pp. 139–143, 2007.

[22] L. Groenesteijn, R. P. Ellegast, K. Keller, F. Krause, H. Berger, and M. P. de Looze, "Office task effects on comfort and body dynamics in five dynamic office chairs," *Applied Ergonomics*, vol. 43, no. 2, pp. 320–328, 2012.

[23] L. McLean, "The effect of postural correction on muscle activation amplitudes recorded from the cervicobrachial region," *Journal of Electromyography and Kinesiology*, vol. 15, no. 6, pp. 527–525, 2005.

[24] G. Jull, D. Falla, J. Treleaven, M. Sterling, and S. OLeary, "A therapeutic exercise approach for cervical disorders," *Boyling JD, Jull G, editors. Grieves modern manual therapy: the vertebral column. Elsevier: United Kingdom*, 2004.

[25] A. P. Claus, J. A. Hides, G. L. Moseley, and P. W. Hodges, "Is 'ideal' sitting posture real?: Measurement of spinal curves in four sitting postures," *Manual Therapy*, vol. 14, no. 4, pp. 404–408, 2009.

[26] "Personal communication with assistant professor of the faculty EWI and HMI at the University of Twente, Angelika Mader, 2018."

[27] N. Rao and A. Aruin, "Auxiliary sensory cues improve automatic postural responses in individuals with diabetic neuropathy," *Neurorehabil Neural Repair*, vol. 2, no. 25, pp. 110–7, 2011.

[28] C. Redd and S. Bamberg, "A wireless sensory feedback device for real-time gait feedback and training," *IEEE/ASME Trans Mechatronics*, no. 17, pp. 425–33, 2012.

[29] C. Wall, M. S. Weinberg, P. B. Schmidt, and D. E. Krebs, "Balance prosthesis based on micromechanical sensors using vibrotactile feedback of tilt," *IEEE Trans Biomed Eng*, vol. 48, pp. 1153–1161, 2001.

[30] R. K. Yin, *Case study research: design and methods.* Sage Publications, 1989.

[31] D. L. Burnier, "Encounters with the self in social science research: A political scientist looks at autoethnography," *Journal of Contemporary Ethnography*, vol. 35, no. 4, pp. 410–418, 2006.

[32] S. Denshire, "On auto-ethnography," *Current Sociology Review*, vol. 62, no. 6, pp. 831–85, 2014.

[33] P. Burdell and B. B. Swadener, "Critical personal narrative and autoethnography in education: Reflections on a genre," *Educational Researcher*, vol. 28, pp. 21 – 26, 1999.

[34] "Inrichting computerwerkplek - ergonomie site." [Online]. Available: http://www.ergonomiesite.be/computerwerkplek/

[35] F. Gemperle, C. Kasabach, J. Stivoric, M. Bauer, and R. Martin, "Design for wearability," in *Digest of Papers. Second International Symposium on Wearable Computers (Cat. No.98EX215)*, 1998, pp. 116–122.

[36] C. Zeagler, "Where to Wear It: Functional, Technical, and Social Considerations in On - Body Location for Wearable Technology 20 Years of Designing for Wearability," *International Symposium on Wearable Computers. Maui, Hawaii*, 2017.

[37] H. Profita, J. Clawson, S. Gilliland, C. Zeagler, T. Starner, J. Budd, and E. Yi-Luen, "Dont mind me touching my wrist: A case study of interacting with on-body technology in public," in *ISWC13, September 912, 2013, Zurich, Switzerland*, pp. 89–96.

[38] M. R. Parks, "Where does scholarship begin?" 1997. [Online]. Available: http://ac-journal.org/journal/vol1/Iss2/special/parks.htm

Appendix I

Interview physiotherapist

To gain knowledge in the topic of ergonomically correct postures, an extensive interview is executed with physiotherapist Christine Hulst [20]. An English, summarized version with the essential gained knowledge, can be found in section 2.1.

I.1 Drie stappen voor een goede houding

Om uit te leggen hoe een goede houding gevormd kan worden, is het handig om eerst te weten hoe een slechte houding gevormd wordt. Het eerste wat gebeurd, is dat het bekken naar achter gekanteld wordt. Hierdoor gaat het lumbale deel van de wervelkolom, zie figuur I.1, automatisch mee naar achteren. Doordat de hele rug naar achteren gaat hangen verschuifd het zwaartepunt van het lichaam. Tenzij er spraken is van extreem sterke buikspieren, zal de persoon achterover vallen. Ter compensatie buigt het lichaam automatisch het bovenste deel, het thoracale deel, van de wervelkolom naar voren, hierdoor komt het zwaartepunt weer goed te liggen maar wordt ook een bolle rug gevormd. Door de verandering van de thoracale wervelkolom, gaat de cervicale wervelkolom ook naar voren, waardoor het hoofd naar beneden knikt. Echter, willen we graag op een computer scherm kijken, dus de kin wordt naar voren uitgestoken waardoor het hoofd weer naar voren kan kijken, echter wordt hierdoor forwardheading gevormd, wat slecht is voor de spieren in de nek. Een ander effect van de nieuwe vorm van het thoracale deel van de wervelkolom is dat de schouderbladen naar de zijkant van de torso. Dit alles samen is een slechte houding die vaak aangenomen wordt als mensen zittend werken.

Om de slechte houding te vervangen voor een goede houding, moeten er drie stappen worden uitgevoerd. De eerste stap is het correct kantelen van het bekken. Deze moet in de neutrale positie/licht naar voren gekanteld staan. Doordat het bekken rechtop staat, beweegt

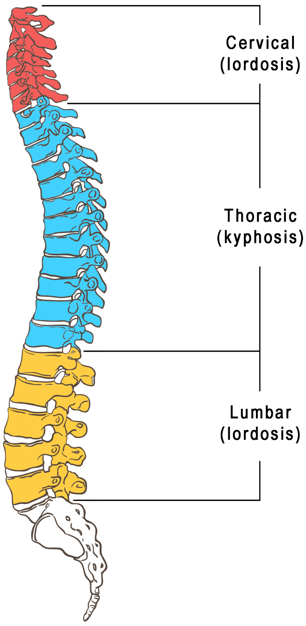


Figure I.1: Cervicaal, Thoracaal & Lumbaal deel van de wervelkolom

het lumbale deel van de wervelkolom hier automatische achteraan. Wanneer deze eerste stap is uitgevoerd, is de helft van de correct houding is al gevormd. De compensatie van het thoracale deel van de wervelkolom is nu namelijk niet meer nodig en kan heel makkelijk opgeheven worden door de tweede stap uit te voeren.

De tweede stap voor het vormen van een goede houding, is het naar beneden en lichtelijk naar binnen drukken van de onderste punten van de schouderbladen (Angulus Inferior). Een geheugensteuntje hiervoor is dat de punten richting de BH sluiting moeten wijzen.

Nu is alleen nog het cervical deel van de wervelkolom en het hoofd niet goed geplaatst. Om dit te verhelpen moeten de cervicale wervels bovenop elkaar geplaatst worden zodat het hoofd op de hele wervelkolom kan balanceren.

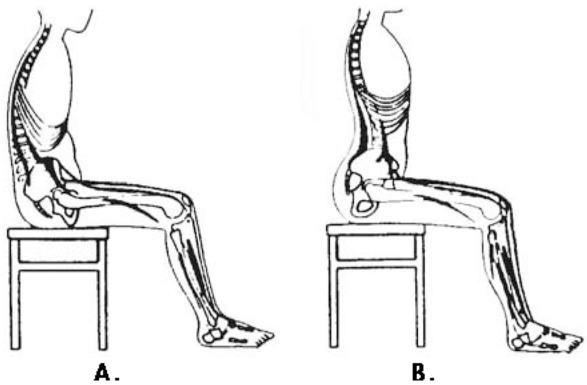


Figure I.2: Slechte houding (a.) Correcte houding (b.), afbeelding door Lotte de Vos

I.2 Factoren van een goede houding

Er zijn heel wat factoren die invloed hebben op de houding van het menselijk lichaam. Er zijn drie lichamelijke factoren die de houding beinvloeden:

1. Vorm van de botten
2. Tussenwervelschijf
3. Spieren

De vorm van de botten is van invloed op een goede houding, echter kunnen we niet veel doen aan de vorm, dit is genetisch bepaald. Tussenwervelschijven zijn de plakken kraakbeen die, zoals de naam al zegt, liggen tussen de wervels van de rug. Deze tussenwervelschijven zijn het flexibele deel van de wervelkolom, ze kunnen vervomen waar nodig en ze vangen, samen met de vorm van de wervelkolom, de klappen op die de rug ontvangt van de omgeving. Wanneer mensen ouder worden, worden deze tussenwervelschijven minder flexibel en vooral platter, waardoor ze minder effectief worden en de wervels kunnen beschadigen, zie figuur I.3. Zoals eerder al genoemd, heeft de vorm van de wervelkolom heel veel invloed op zijn functioneren. Van onder naar boven vormt hij een lordosis, kyphosis, lordosis, zie figuur I.1. Hierdoor werkt het als een veersysteem. In plaats van een stok die op den duur zou breken en langs elkaar schieten, als er te veel druk op komt, kan de wervelkolom nu klappen opvangen doordat hij mee kan veren. De derde factor die heel veel effect heeft op een correcte houding, zijn de spieren. Deze moeten krachtig zijn, maar niet te krachtig, ze moeten niet bepaald functies overnemen van andere spieren, meer hier over in sectie I.3.1

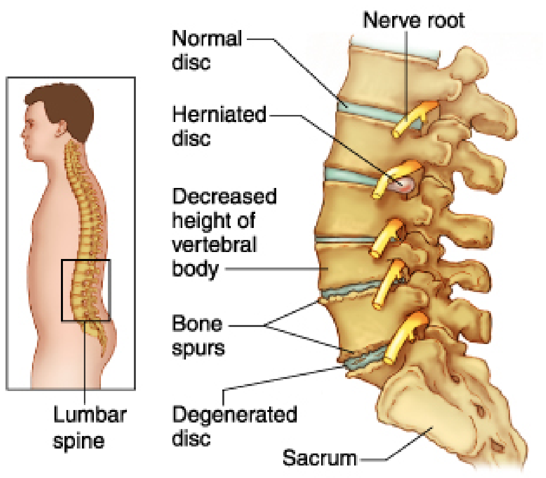


Figure I.3: Tussenwervelschijf slijtage, afbeelding door Doctors pain relief system

Naast lichamelijke factoren, zijn er ook factoren in de omgeving die een goede houding benvloeden:

1. Zitvlak van de stoel
2. Toetsenbord hoogte
3. Beeldschermhoogte

Het zitvlak van de stoel moet zo'n hoogte hebben dat de heup een hoek kan vorm van 90 graden of meer. Hierdoor kan het bekken in de juiste positie staan en kan er gemakklijk een lumbale correctie uitgevoerd worden. De tafel, en dus het toetsenbord, moet op elleboog hoogte afgesteld zijn. Hierdoor worden de armen ondersteund, wat weer 10% van het lichaamgewicht scheelt [34]. De hoogt van het beeldscherm is heel belangrijk voor de juiste stand van de cervicale wervels. Wanneer het beeldscherm te laag is, gaat het hoofd voor het lichaam hangen, waardoor de cervical wervels naar voren worden geschoven ten opzichte van elkaar. Wanneer het beeld scherm te hoog is wordt het hoofd in de nek gelegd waardoor er te veel constante druk kom op de achterkant van de tussenwervelschijven. Een correcte hoogte van het beeldscherm is wanneer de gebruiker de bovenste rand van het beeldscherm ziet, waneer hij/zij recht vooruit kijkt [34].

I.3 Spieren

I.3.1 Extrensieke & intrinsieke spieren

De ruggenwervelkolom bevat zowel grote (extrinsieke/globale) als kleine (intrinsieke/lokale) spieren. Kleine spieren verbinden de wervels onderling. Deze spieren zijn noodzakelijk voor een goede houding. Wanneer spieren worden vergeleken met hardlopers, zijn de intrinsieke spieren de marathon lopers. Ze kunnen het ontzettend lang uithouden, maar kunnen niet heel veel vermogen leveren.

Grote spieren lopen langs de hele ruggenwervelkolom en zijn verbonden aan alle wervels. Deze spieren zijn voor de snelle bewegingen en bewegingen die veel kracht nodig hebben. Dit zijn de sprinters, ze kunnen heel veel kracht leveren, maar kunnen dit niet voor een lange periode. Als het lichaam dit wel eist, verzuren ze en wordt het lichaam stijf op die plek/in die spier, wat pijn veroorzaakt.

Het is heel belangrijk dat de kleine spieren hun werk goed doen. Ze moeten een goede coordinatie hebben, dat ze dus goed weten wat ze moeten doen en ze moeten een goed uithoudingsvermogen hebben, want ze moeten de kracht voor een hele lange tijd leveren. Kleine spieren bepalen hoe de wervels liggen ten opzichte van elkaar.

Om van rugpijn af te komen dat wordt veroorzaakt door een verkeerde houding moeten de kleine spieren getraind worden. Als een kleine spier bij een bepaalde wervel niet goed zijn werk doen, moet deze getraind worden en niet de grote spier. Als de grote spier wordt getraind, neemt deze de taak over van de kleine spier en dan wordt deze kleine spier helemaal slap en wordt het probleem dus alleen maar erger.

I.3.2 Spieren rug

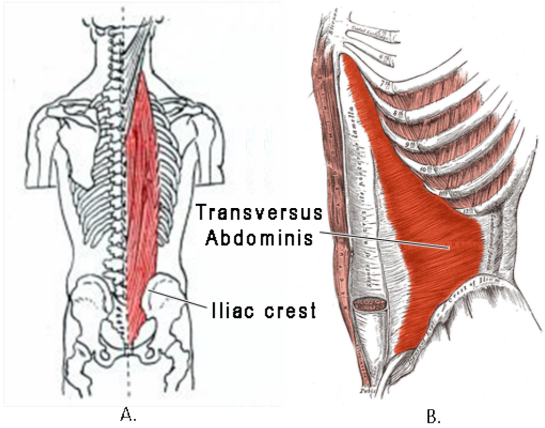


Figure I.4: Erector Spinae (posterior) & Transversus Abdominis (anterior)

De rug heeft twee grote spieren (Erector Spinea, zie figuur I.4(a.)), deze lopen aan weerszijden langs de hele wervel kolom. De spieren zitten onderaan de rug vast aan de kam van het bekken (Illiac crest) en lopen via alle wervels door tot in de nek. Ze zijn dus verbonden met elke wervel via de twee uitsteeksels aan weerszijdes van de wervel, de Transverse Process, zie figuur I.5. Omdat deze spieren aan alle wervels vast zitten hebben ze dus ook invloed op alle wervels. Echter, wanneer er een zwakke instabiele wervel tussen zit, hebben de spieren daar het meeste invloed op.

I.3.3 Buikspieren

Naast de grote en kleine spieren in de ruggenwervelkolom, is het ook essentieel dat de diepe dwarse buikspieren (Transversus abdominis, zie figuur I.4(b.)) goed getraind zijn. De

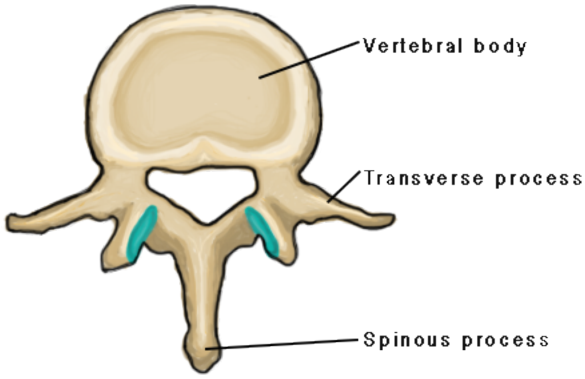


Figure I.5: Lumbar vertebra L2

diepe dwarse buikspieren lopen als een ceintuur om het lichaam en ondersteunen dus de houding. Vanaf het huidoppervlak naar binnen in het lichaam liggen de spieren als het volgt:

- Rechte buikspieren, de vezels lopen verticaal
- Schuine buikspieren, de vezels lopen diagonaal
- Diepe dwarse buikspieren, de vezels lopen horizontaal

Als de houding niet goed is, ontstaat er overbelasting van bepaalde spieren. Dit leidt tot pijn in twee verschillende regio's:

- Pijn in spieren die overbelast/overmatig gerekt zijn
- Pijn in gewrichten

I.4 Schouder

Wanneer de houding aangenomen wordt waarbij de rug bol staat, heeft dit niet alleen effect op de rug, maar ook op schouders. De schouders bladen (Scapulae) worden dan meer naar de zijkant van de torso geduwd en draaien ook naar buiten, waardoor de punten aan de onderkant van de schouderbladen (Angulus Inferior) naar buiten wijzen. Dit heet antro positie, antro = voor. Dit heeft veel invloed op de nekspieren, deze lopen dan ineens niet meer van de achterkant van de rug naar de schedel achter het oor, maar lopen van de zijkant van de rug en draaien in de nek richting de schedel achter het oor. De trapezius is de spier die het schouderblad weer goed trekt.

I.5 Hoofd

Verkeerde positie van de lumbale en of thoracale wervels zorgen niet alleen voor de antro positionering van de schouders, maar ook die van het hoofd. Het hoofd weegt 5kg en moet balanceren op de wervelkolom als een kogel op een buis. De incorrecte houding van het hoofd komt doordat de lumbale wervels verkeerd staan. Het is namelijk allemaal actie reactie doordat de rug bol staat gaan de nek naar voren hangen en knikt het hoofd automatisch naar beneden. Maar omdat er dan tijdens het werken op een computer scherm het hoofd opgelicht moet worden om iets te kunnen zien, wordt de kin naar voren gestoken wat een slechte houding van de cervicale wervels veroorzaakt. Spieren moeten dus extra gestrekt worden waardoor er spanning op de spier komt te staan en de bloedvaten nauwer worden.

I.6 Oefeningen

Er zijn oefeningen die uitgevoerd kunnen worden voor een betere houding:

- Bekken kantelen en onderrug goed positioneren
- Dwarse buikspieren trainen
- Reminder tape om de scapula goed in houding te houden
- Nek spieren trainen (de kleine spieren)
  - Met een lasertje op het hoofd een patroon op een a4 papier op de muur volgen
  - Oefeningen bij de fysio, waar tegen druk gegeven moet worden op de plek waar de physiotherapeut's vingers op een wervel drukken. Dit moet echter wel gedaan worden met de kleine spieren en niet met de grote.

Appendix II

Lumo Lift

To get familiar with wearable technology and to get insight into haptic feedback, the Lumo Lift [7] is worn. This appendix depicts the results of the research of the Lumo Lift.

II.1 Profile

In order to have optimal posture coaching, a profile needs to be set up at the begin of using the Lumo Lift.

Gender: Female
Height: 173 cm
Weight: 65 kg
Birthday: 22 September 1997
Goal: Other

II.2 Log

While wearing the Lumo Lift, a log is kept, here all thoughts and opinions about the Lumo Lift are depicted. The Lumo Lift is worn more often than the days stated in this section, but some days there were no new opinions on the Lumo Lift.

23 February 2018
Vibration Strength: *HIGH*
Feedback Delay: *30 seconds*

The haptic feedback is quite disruptive during the reading of an article. The measurements is very accurate, you often think you are sitting correct, but than you still get feedback. Often there is only a very small movement needed to create a proper posture again. The feedback is annoying when you think you are already sit correct.

---

1 March 2018
Vibration Strength: *HIGH*
Feedback Delay: *30 seconds*

During daily life activities the feedback tends to be a bit annoying. I find myself often thinking, *"Nah I'll change my position in a bit"*. It is less disruptive when a vibration comes while executing everyday activities, than during activities which require a lot of concentration. With the use of the application, it becomes a bit of a challenge or game to have a correct posture for (almost) 100 percent of the time.

---

2 March 2018
Vibration Strength: *HIGH*
Feedback Delay: *30 seconds*

I am getting used to the vibrations, and already receive less feedback which means that my body is already attaining a better posture from itself. Also a bit of a Pavlov effect appears, while thinking of the Lumo Lift already triggers getting into a correct position.

---

5 March 2018
Vibration Strength: *HIGH*
Feedback Delay: *30 seconds*

Needs a lot of recalibration today, which is annoying. It feels like the accuracy changes per day, a possibility for this might be that it depends on the fit of the garment (tight or loose fit)

---

8 March 2018

Vibration Strength: *HIGH*

Feedback Delay: *30 seconds*

It is annoying to get feedback during lectures while it is disturbing but it also makes a lot of noise. It has the same level of annoyance of a vibrating smartphone that lies on a table.

---

12 March 2018

Vibration Strength: *HIGH*

Feedback Delay: *30 seconds*

It is annoying that the Lumo Lift gives feedback while attaining the posture that is explained by the physiotherapist.

II.3 Desirability of haptic feedback

Table II.1 shows during which events it is desirable and during which events it is undesirable to receive haptic feedback while wearing the Lumo Lift.

	Feedback desirable	Feedback undesirable
Studying	X	–
Dining	X	–
Meetings:	–	–
- Casual	X	–
- Official	–	X
Driving a car	–	X
Supermarket trip	X	–
During an exam	–	X
Lecture	–	X
Tutorial session	X	–

Table II.1: The desirability of haptic feedback during specific events

Appendix III

Workbook

The ideation phase of this project is filled with all sorts of experiments. Chapter 4 contains the summary of the experiments. This appendix depicts all these experiments, with their goal, observations, and conclusions.

III.1 Postures

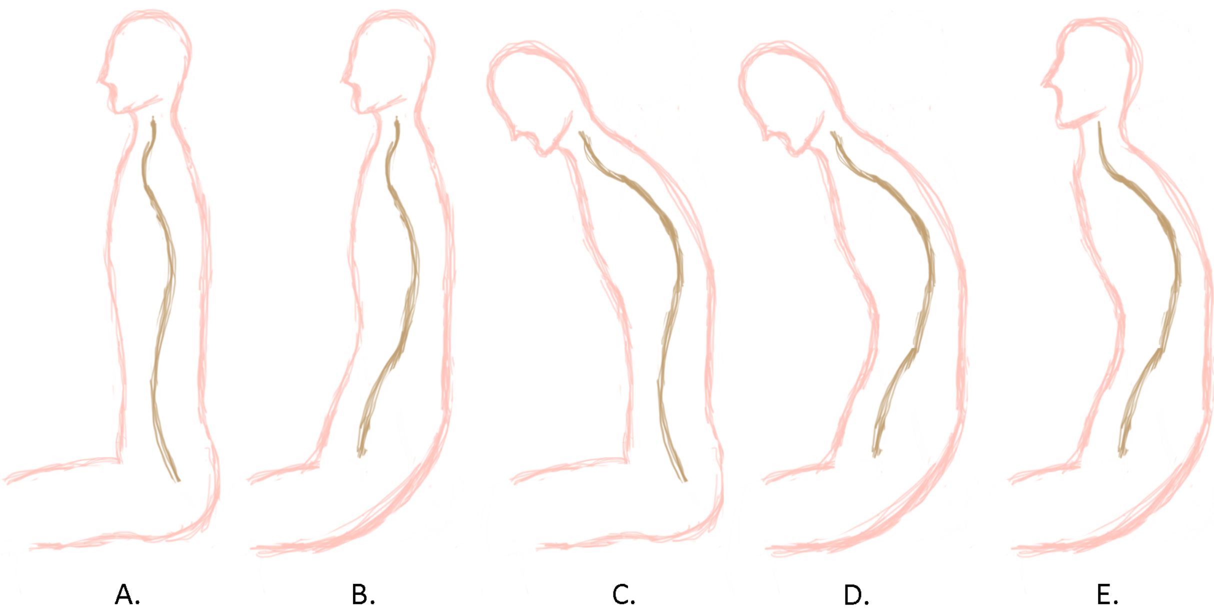


Figure III.1: Postures (a.) Sitting up straight (b.) Incorrect lumbar spine (c.) Incorrect thoracic spine (d.) Slouching posture (e.) Slouching with head lifted up

III.2 Sensors

III.2.1 Two accelerometers on a stick

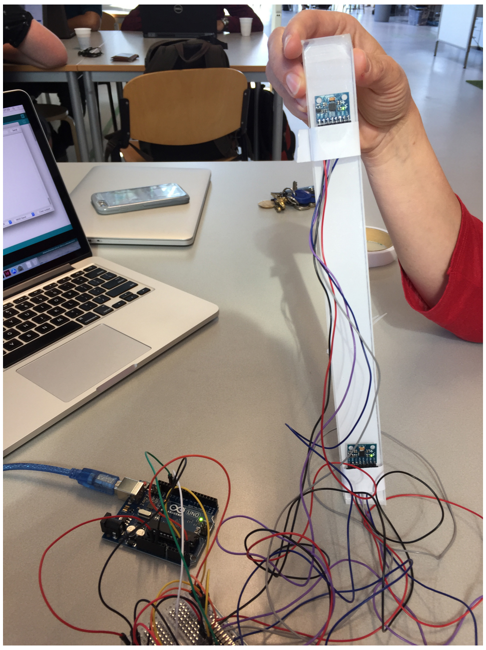


Figure III.2: Two accelerometers on a stick

Goal: Check whether or not the delta value of two accelerometers placed above each other is 0 (or close to 0).

Observations/insights:

Minimum delta value : 110

Maximum delta value : 1800

When the stick lies on the table the values stay quite steady with a maximum deviation of 100. When the stick is moved, the values have a much bigger deviation than 100.

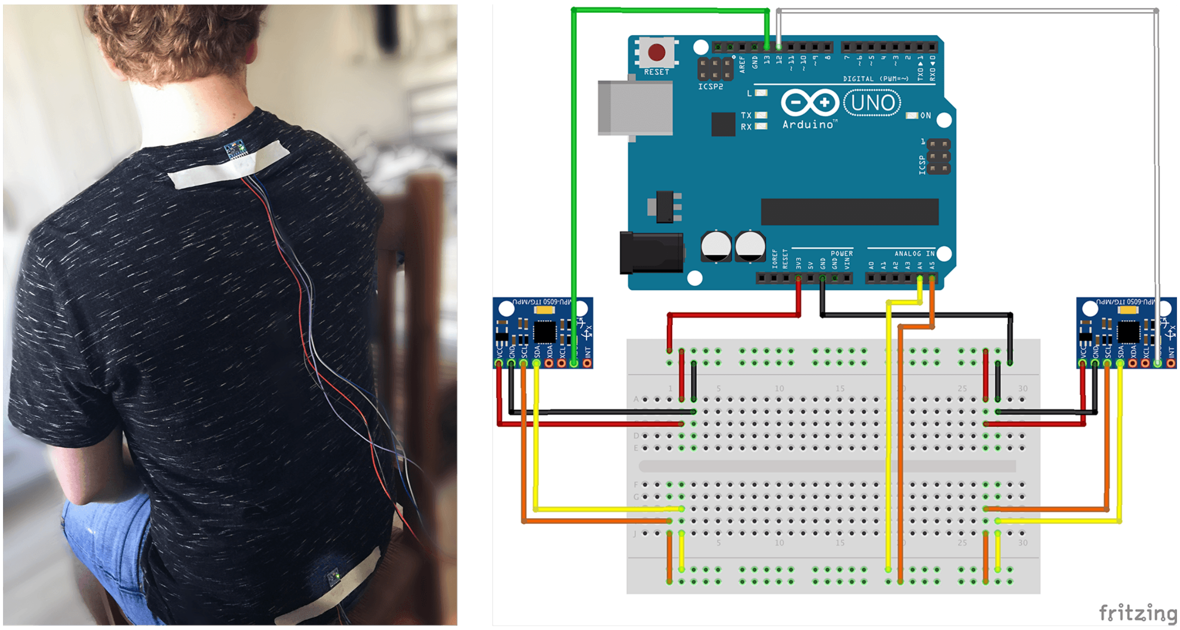
When the stick is hold vertical, the minimum value gets the closest to 0 (-110).

Conclusion: A delta value of 0 is not attained and there are large deviations, this should be taken into account with respect to the threshold of giving feedback.

III.2.2 Accelerometers at top and bottom of the back

Goal: Find out what the difference (delta) between the two accelerometers is, while attaining the seated postures of figure III.1. The sensors are place on the top and at the bottom of the back, see figure III.3.

Observations/insights: For the raw data see table III.1. When sitting still, the values



A. B.

Figure III.3: (a.) Accelerometers at top and bottom of the back (b.) Two accelerometers hardware setup

have a maximum deviation of approximately 100, as with experiment III.2.1. However, when heavily breathing, yawning, or the movement of one of the limbs, the values already change a lot.

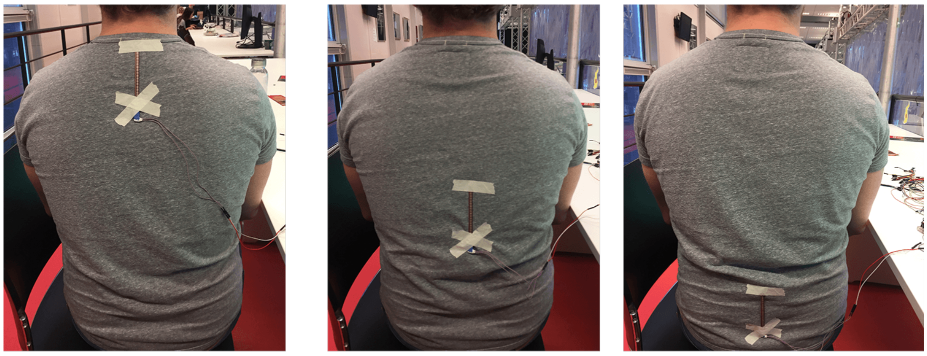
Conclusion: Because the values change a lot when not sitting completely still, a proper threshold has to be added to the feedback system. Looking at the raw data, there could be implemented a statement that if the delta is between 1700 & 1800 there should be given feedback, and also when the delta is bigger than 3550.

When there are multiple actuators at multiple spots on the body, there could also be looked at the data and give only feedback on that specific spot on the body. Then there has to be an actuator to fix all the four incorrect posture.

	Minimum delta value	Maximum delta value
Sitting up straight	2000	2100
Incorrect lumbar spine	1700	1850
Incorrect thoracic spine	4400	4700
Slouch	5100	5600
Slouch head lifted	3550	3700

Table III.1: Raw data from experiment III.2.2: Accelerometers at top and bottom of the back

III.2.3 Flex sensor



A. B. C.

Figure III.4: Flex sensor placement (a.) Upper back (b.) Middle back (c.) Lower back

Goal: Find out whether or not a flex sensor has an extra value to posture measuring. Different placements of the bending sensor are top of the back, halfway the back & bottom of the back.

The mapping of the data is done with the use of the following statement:
flex=map(flexSensorReading, 400, 660, 0, 100);

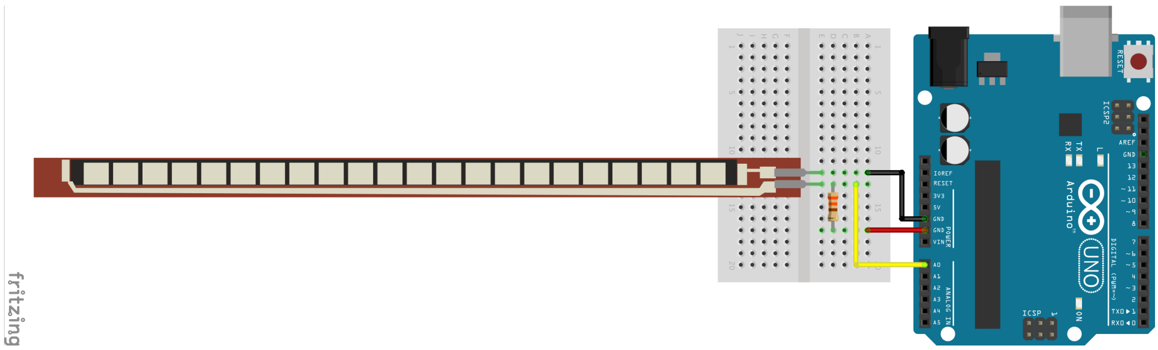


Figure III.5: Flex sensor hardware setup

Observation/insights:

	Raw value	Mapped value
Sitting up straight	640	91
Incorrect lumbar spine	640	91
Incorrect thoracic spine	637	91
Slouch	637	91
Slouch head lifted	590	74

Table III.2: Raw data from part one of experiment III.2.3: Flex sensor at the top of the back

	Raw value	Mapped value
Sitting up straight	632	89
Incorrect lumbar spine	600	77
Incorrect thoracic spine	671	104
Slouch	675	105
Slouch head lifted	675	105

Table III.3: Raw data from part two of experiment III.2.3: Flex sensor at the middle of the back

	Raw value	Mapped value
Sitting up straight	680	107
Incorrect lumbar spine	675	105
Incorrect thoracic spine	671	104
Slouch	675	105
Slouch head lifted	675	105

Table III.4: Raw data from part three of experiment III.2.3: Flex sensor at the lower part of the back

For the raw data see tables III.2, III.3 & III.4. The data is very constant, in other words, not as fluctuating as the accelerometer. However, there is so little difference shown in the sensor data between the different (in)correct postures, that a distinction between the postures cannot be made on the base of the data. The sensor has to be very tight to the body, otherwise it does not work.

Conclusion: The flex sensor does not give a large variety in data and has to be very tight to the body. Which makes it, to my idea, not suitable for measuring postures.

III.2.4 Two accelerometers at the pelvis

Goal: Finding out whether or not posture can also be measured with two accelerometers above and below the pelvis.

Observations/insights: For the raw data see table III.5.

	Minimum delta value	Maximum delta value
Sitting up straight	2000	2400
Incorrect lumbar spine	9400	9800
Incorrect thoracic spine	2400	2900
Slouch	7700	8000
Slouch head lifted	7900	8100

Table III.5: Raw data from experiment III.2.4: Accelerometers at top and bottom of the pelvis

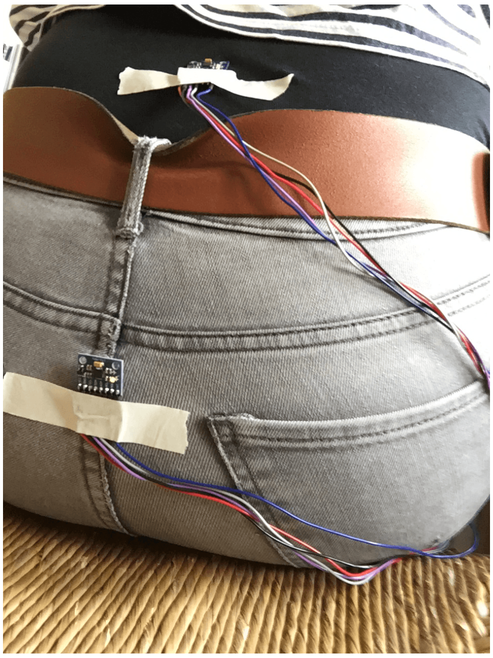


Figure III.6: Two accelerometers at the pelvis

Conclusion: Comparing the values of this experiment with the values of experiment III.2.2, only posture (a.) has a resemblance. The other postures their values do not really resemble, however, the values of this experiment are higher (except for posture c.), which could be more convenient for the threshold. While there can be made a statement that when the data is above, for example 7700, it is a poor posture. Hereby the thoracic incorrect posture is skipped, but this posture is very hard to take on, so will probably not be taken on without an incorrect lumbar spine.

III.2.5 Two accelerometers at the pelvis and one at the top of the back

	Min. value back	Max. value back	Min. value pelvis	Max. value pelvis
Sitting up straight	8000	8200	23500	24500
Incorrect lumbar spine	11100	11600	16200	16700
Incorrect thoracic spine	7000	8400	15100	15800
Slouch	11450	11700	14900	15750
Slouch head lifted	11250	11400	12900	13450

Table III.6: Raw data from the first attempt of experiment III.2.5: Two accelerometers at the pelvis and one at the top of the back

Goal: Check whether or not the accelerometer at the top of the back has extra value to the posture measuring next to the accelerometers at the pelvis.

Observations/insights: For the raw data see tables III.6 & III.7. During the experiment

	Min. value back	Max. value back	Min. value pelvis	Max. value pelvis
Sitting up straight	-14200	-12000	700	1000
Incorrect lumbar spine	800	1300	-4000	-2000
Incorrect thoracic spine	-300	0	-14000	-13200
Slouch	3500	4100	-2050	-1850
Slouch head lifted	3500	3900	-2000	-1500

Table III.7: Raw data from the second attempt of experiment III.2.5: Two accelerometers at the pelvis and one at the top of the back

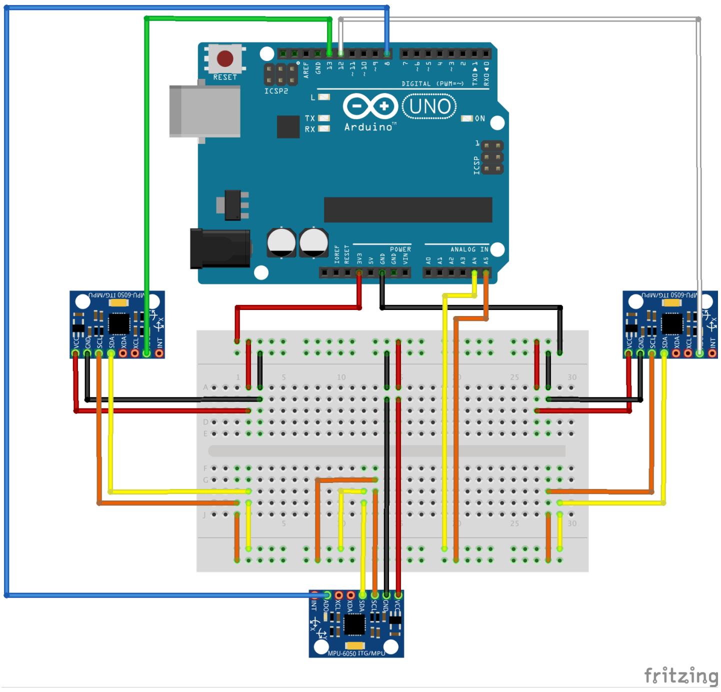


Figure III.7: Three accelerometers hardware setup

the data seemed to be very fluctuating.

Conclusion: The data of both experiments are so different, so no solid conclusion can be drawn from this. Three accelerometer connected to an Arduino Uno in this way does not give reliable data.

III.2.6 The best way to measure posture

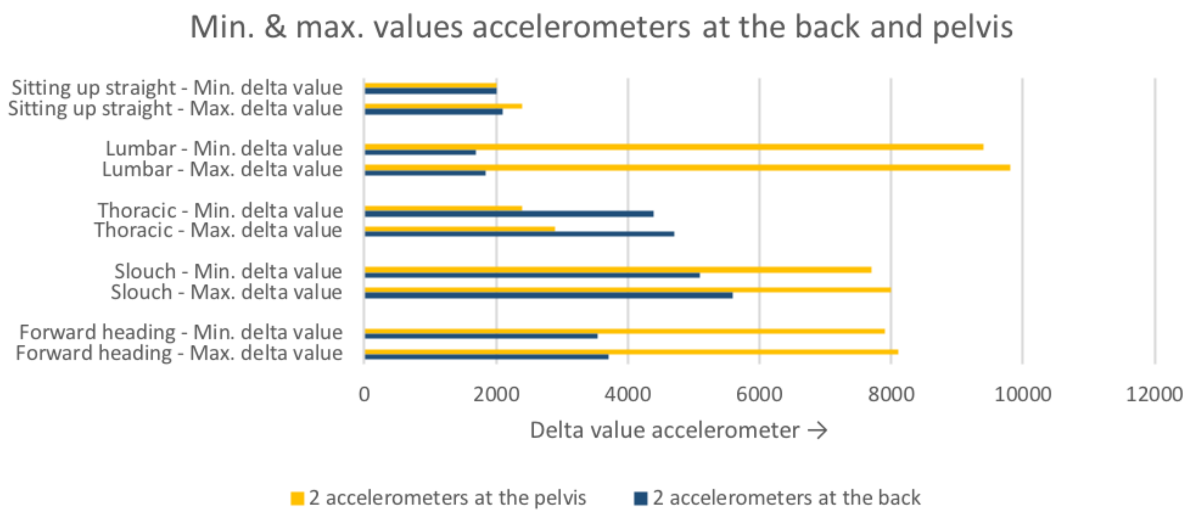


Figure III.8: Comparison of experiment III.2.2 and III.2.4, clustered bar graph

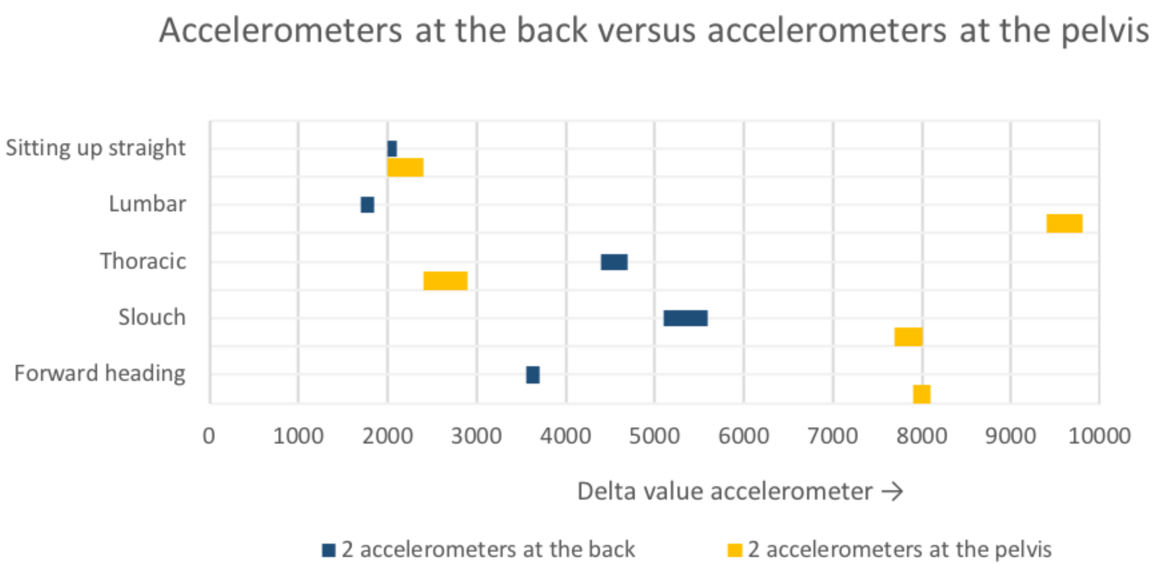


Figure III.9: Comparison of experiment III.2.2 and III.2.4, floating clustered bar graph

In order to get a better overview of the possibilities to measure posture, experiment III.2.2 and III.2.4 are compared in multiple graphs, see figures III.8, III.9 & III.10. Graph III.9 show the difference between the placement of two accelerometers at the back versus two accelerometers at the pelvis the best. At the pelvis there is a big difference between a good posture and a poor posture, data-wise. With the two accelerometers at the back (blue in graph III.9) a good posture lies at 2000, and a poor posture starts at 3500. The difference between these is very small. Where with the two accelerometers at the pelvis (yellow in graph

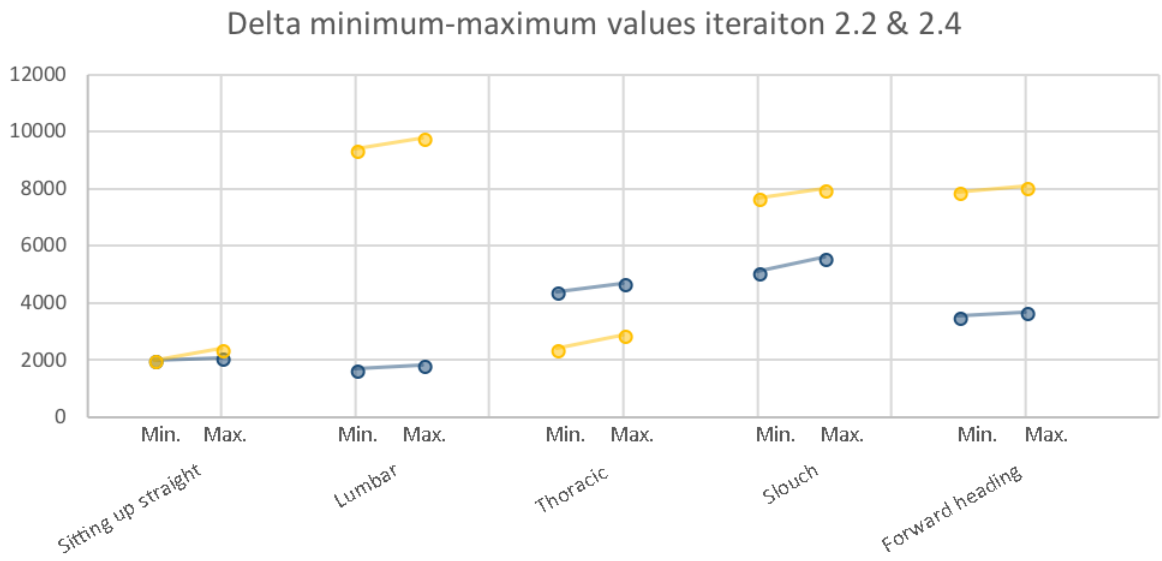


Figure III.10: Comparison of experiment III.2.2 and III.2.4, scatter with straight lines and markers

III.9) a good posture lies at 2000, and a poor posture starts at approximately 7750. The difference between a good and a poor posture is thus much bigger data-wise, and therefore, more suitable for measuring posture.

III.3 Haptic feedback

III.3.1 Bone or muscle

Goal: Perceive the difference between a vibration on the bone and a vibration motor on the muscle.

For this experiment a bone and muscle in the leg is chosen, while the leg was easily accessible for autoethnographic research.

Observation/insights: The vibration is felt more intense on the bone than on the muscle. The vibration on the bone is felt throughout the whole bone (and goes further in other bones), with the muscle it is only that spot of the muscle. The vibration on the bone is a less pleasant feeling than a vibration on the muscle.

Conclusion: Vibration on the bone is felt more intense but also less pleasant in comparison with the muscle. This experiment is executed on the leg, an additional experiment should be executed on the back as well, to see if that gives the same result. There needs to

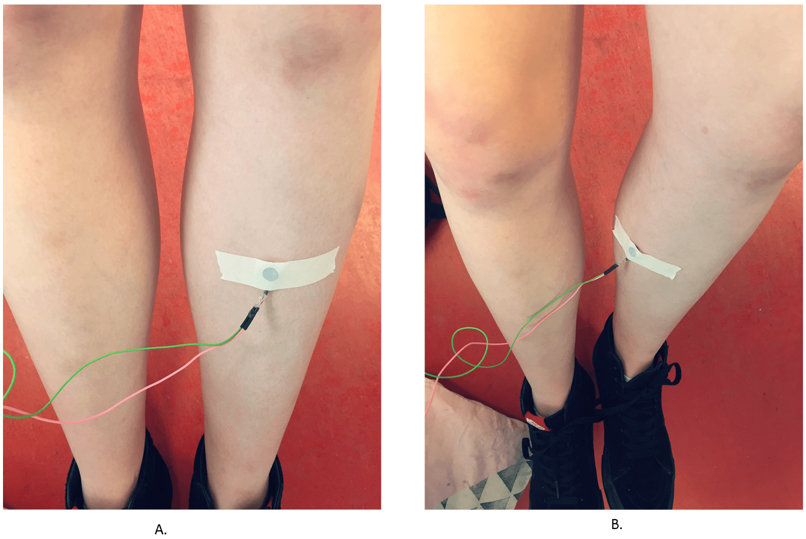


Figure III.11: Vibration motor on (a.) Bone and (b.) Muscle

be taken into account the the pelvis (bone) is less on the skin surface as the bone in the leg.

III.3.2 Pattern with two vibration motors

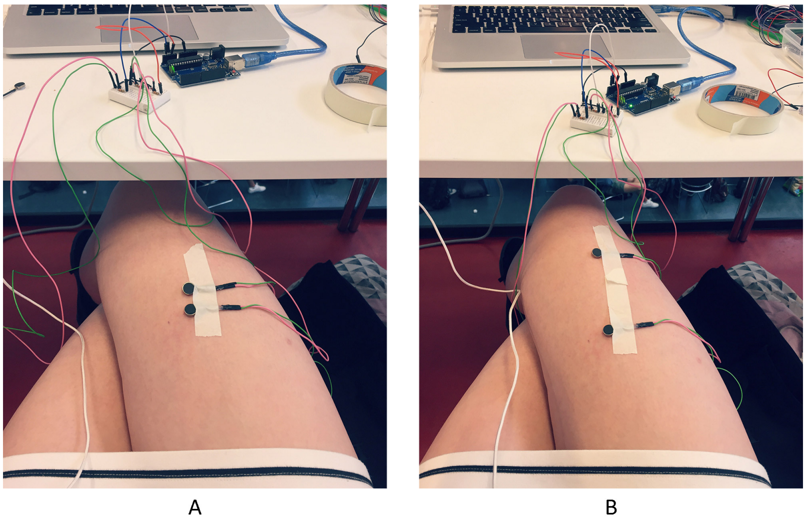


Figure III.12: Vibration motors approximately (a.) One centimeter apart (b.) Ten centimeter apart

Goal: Finding out whether a pattern created with two vibration motors can give an uplifting effect.

Observation/insights: The vibrational intensity is very low, which makes them in general not very noticeable. With two motors near each other, the effect of a pattern is hardly felt, only when there is really focused on that there is a vibration, a pattern can be distinguished. But because the motors are placed near each other, the effect of the motors is felt more. With two motors about ten centimeter apart from each other, a pattern can more easily be noticed, however, while the vibration motors their intensity is very low, the effect from the pattern is also very low.

Conclusion: There should be looked into how to increase the intensity of the motor. Or looked into other ways to provide haptic feedback. When the effect of the vibration becomes more intense, a pattern of several motors might be very efficient on the sacrum (lowest bone of the spine), this needs to be tested.

Edit: In experiments III.3.5 and III.3.7, a part of this experiment is repeated (with more intense vibrational motors).

III.3.3 Vibration dispersing material

Goal: See whether or not several types of material spread out or increase the vibration.

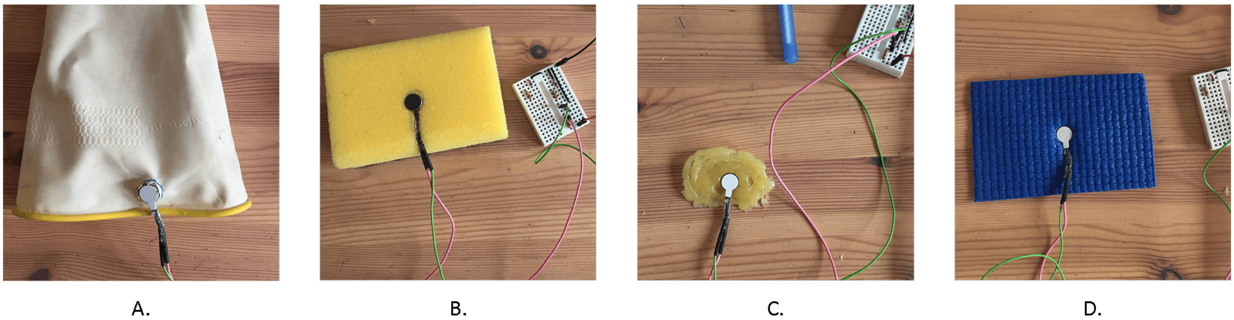


Figure III.13: Vibration dispersing material with vibration motor (a.) latex (b.) sponge (c.) hot glue gun (d.) foam

Observations/insights:

Sponge: Increases the effect of the motor extremely. Increases the vibrational surface. When placed on the back, the vibration is not so strong that is supports a movement, is it more like a notification. The vibration is felt stronger at the bottom of the scourer than at the top.

Foam: Increases the effect of the motor. Increases the vibrational surface efficient, vibration does not decrease to the sides. When placed on the back, the vibration is hardly felt. The foam isolates the vibration once in a while. Flexible material and thus takes the shape of the body properly.

Latex: Hardly increases the effect of the motor. When you loosely hold it in your hands the vibration can be felt in the surface, but when the slightest tension is applied to the material, no vibration is felt anymore. Hardly increases the vibrational surface. When placed on the back, the vibration is not felt. The latex isolates the vibration once in a while.

Hot glue gun: Increases the effect of the motor extremely, slightly more than the sponge. Increases the vibrational surface efficient, vibration does not decrease to the sides. When placed on the back, the vibration is not so strong that is supports a movement, is it more like a notification.

Conclusion: From best to worst it is: Hot glue gun, Sponge, Foam, Latex gloves. A combination should be made between the hot glue gun, sponge and foam. While the hot glue gun had the best intensity of the motor increasement, but is very inflexible. The foam is very flexible, but does not increase the effect of the motor as much as the hot glue gun and the sponge.

Edit: After the discovery that the way the vibration motor was connected to the power, decreased the intensity of the motor, the four experiments of this iteration were re-executed. A reconsideration of the previous gained knowledge can be found in the following section. An additional experiment is executed by putting the vibration motor in a thick piece of felt.

Figure III.14: Vibration dispersing felt

Sponge: Increases the effect of the motor extremely. Increases the vibrational surface. The vibration is felt stronger at the bottom of the scourer than at the top.

Foam: Increases the effect of the motor. Increases the vibrational surface efficient, vibration does not decrease to the sides. Flexible material and thus takes the shape of the body properly.

Latex: It does increase the effect of the motor, when it is loosely hold in the hands, the edges (yellow in figure III.13) give the most vibrational effect, the other part (white in figure III.13) has more tension, and thus does not radiate the vibration as effective as the edges. It increases the vibrational surface.

Hot glue gun: Increases the effect of the motor extremely, slightly more than the sponge. Increases the vibrational surface efficient, vibration does not decrease to the sides.

Felt: Increases the effect of the motor extremely. Increases the vibrational surface efficient, vibration does not decrease to the sides. The felt is equally flexible as the foam, but increases the effect of the motor more extremely. Which could make this the combination of the hot glue gun and the foam, as stated in the conclusion above.

Conclusion 2.0: It looks like felts has the good properties for vibration dispersing material. There should be looked into the form of the material and where the vibration motors should be placed.

III.3.4 Preference for vibrational feedback placement

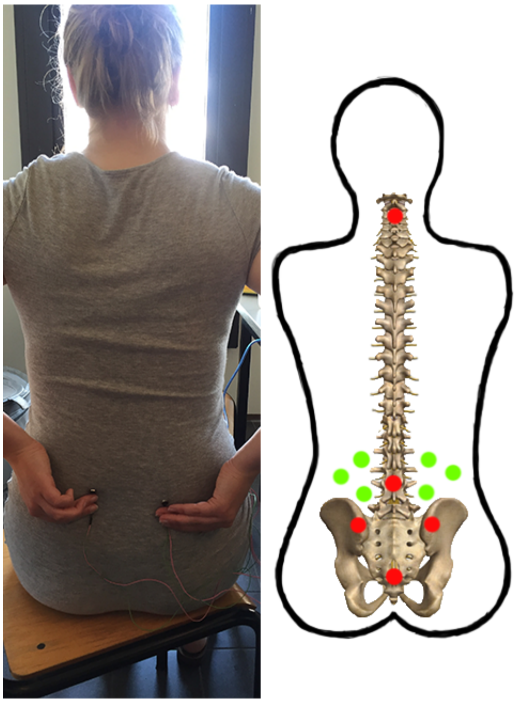


Figure III.15: Preferred placement of vibration motor at the back

Goal: Find out, by placing vibration motor(s) on several spots of the back, which spots are preferred by the researcher & designer to get haptic feedback on.

Observation/insights: The colored spots in figure III.15 are the places that one or multiple vibration motors are held against, applied by someone else, but for the photo, the test subject is holding them herself. The opinion of the researcher & designer is expressed in the colors, red is undesirable and green is a pleasant feeling. The reasoning behind the red spots are:

Neck: The vibration goes through the head and the whole spine, creates temporarily headache when the motor is applied.

Spine: The vibration goes through the whole spine and partly through the pelvis, which feels unpleasant.

Pelvis: The vibration goes through the whole pelvis and radiates to the upper legs, which is perceived as painful.

Sacrum: The vibration goes very intense through the whole pelvis, which triggers the need to go to the bathroom.

The green spots are the area where the vibrational feedback was not unpleasant and triggers a movement, this is basically all over the lower back, just above the pelvis, with the exception of the spine.

Conclusion: This experiment confirms the findings of experiment III.3.1, vibration on the bone is felt more intense but also feel very unpleasant. Vibrational feedback should be applied to the lower back, above the pelvis at both sides of the spine, but making sure that the spine does not get vibrational feedback.

III.3.5 Spot or pattern

Goal: Finding out whether or not there is a preference for the vibration on one spot, at both sides of the spine, or that an upwards pattern is preferred, at both sides of the spine.

This experiment is executed while the vibration motor(s) were placed inside the vibration dispersing felt.

Observation/insights: The vibration does not spread widely through the material when applying to the back, the most of the vibration is felt there where the motor is. A pattern is more stimulating than a vibration on one point (spot vibration). The pattern has to be exactly the same, left and right of the spine, otherwise it is very distracting. A pattern with three vibration motors feels more like a stimulating push than two vibration motors.

Conclusion: A pattern with three vibration motors at both sides of the spine is preferred over a vibration motor on one spot, for the haptic feedback.

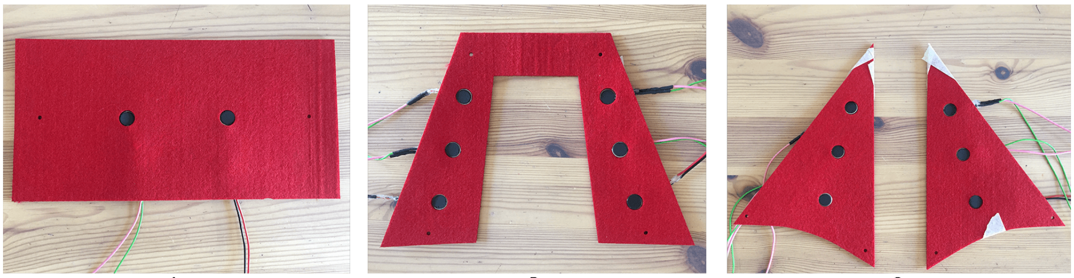


Figure III.16: Vibration motors in vibration dispersing felt

III.3.6 Different shapes of vibration dispersing felt

Goal: Researching what shape is the most ideal for the appliance of haptic feedback

Observation/insights:

Belt (figure III.16(a.)): Way too big, two pieces do not fit on the back. Feels very pleasant, but more like a massage than a stimulation.

Bridge (figure III.16(b.)): Makes a lot of noise. The upside of the bridge triggers the spine. Has to be very tight to the body while it is a big surface. Vibration motors have to be closer to each other to get a better pattern feeling.

Triangles (figure III.16(c.)): Pleasant that the spine is not touched. Points at the side are unnecessary, they are too long and no vibration is felt there. Vibration motors have to be closer to each other to get a better pattern feeling.

Vibration motors do not stay in the felt, there should be made a channel for the wires in order for them to stay in the felt.

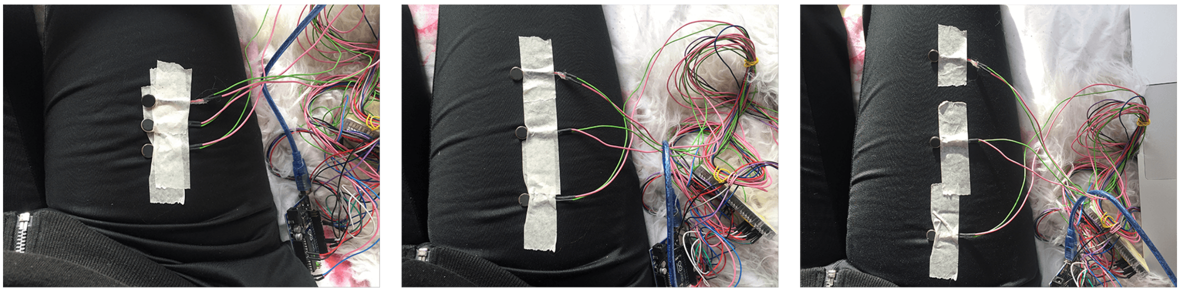
Conclusion: Triangle is the best. Should be adapted so that the vibration motors are closer to each other. Points at the side can be stripped off. It should be more compact, the vibration is mostly felt at the motors, so no big piece of felt is necessary.

III.3.7 Influence of distance for the perception of vibrational patterns

Goal: Researching which distance creates the best perception of a vibrational pattern. This experiment is executed while in the first prototype the distance between the vibration motors was 3.5 centimeter, where the pattern vibration was not always perceived as a pattern. There is such a big gap between one and five centimeter distance while the distance of 3.5 centimeter is thus already researched.

Observations/insights:

One centimeter apart (figure III.17(a.)): The three vibrations together feel, like a spot



A. B. C.

Figure III.17: Distance between vibration motors (a.) one centimeter, (b.) five centimeter, (c.) seven centimeter

vibration with a bigger surface. No pattern is felt.

Five centimeter apart (figure III.17(b.)): A pattern is clearly felt, non-disruptive.

Seven centimeter apart (figure III.17(c.)): A pattern is clearly felt, but the distance between two vibrations is so big that it is slightly disruptive if there is concentrated on something else.

Conclusion: A distance of five centimeter is ideal for the perception of a vibrational pattern, therefore, in the second wearable a distance between the vibration motors of five centimeter will be used.

Appendix IV

Wearable testing

In order to test the prototype wearables, they are worn during a certain test period. While testing, a protocol and log are kept, these are depicted in this appendix.

IV.1 Wearable 1

IV.1.1 Protocol for testing wearable 1

Protocol:

1. Put on the wearable
2. Connect the wearable to the powerbank
3. Calibrate
4. Check if the program works: take on a poor posture for approximately ten seconds
5. Check if the program works approximately each 30 minutes, see step 4
6. Answer the questions, see questions
7. Write down the observations

Questions:

1. How is the wearable worn, with respect to underneath/over clothing?
2. Is the feedback time threshold sufficient?

IV.1.2 Log

While wearing the first wearable, a log is kept, here the questions of the protocol are answered, and all thoughts & opinions about the wearable are depicted.

22 June 2018 *10.15 am - 11.00 am*
Worn: *Over singlet, tail in skinny jeans*
Feedback time threshold: *Okay*

Three vibration patterns every time when receiving feedback, might be a bit too much.
Tested whether or not the wearable stays in place when standing up, no feedback is received while standing which is good!
Wires pop very easy and quick out of the Arduino and breadboard, which is highly annoying.

---

22 June 2018 *00.40 pm - 01.00 pm*
Worn: *Underneath singlet (wearable makes skin contact), tail in skinny jeans*
Feedback time threshold: *Okay*

Felt and wires on the skin feel sweaty and unpleasant.
I get the idea that the accelerometer sometimes touches the skin which makes a short circuit by which the program does not work anymore.
When the sensor at the tail only moves a bit, its data is not on a par with the calibrated data and feedback is given when a good posture is attained.

---

22 June 2018 *01.00 pm - 02.30 pm*
Worn: *Over singlet, tail in skinny jeans*
Feedback time threshold: *Okay*

Vibrations are perceived as pleasant.
When talking to a friend, and not focusing on the wearing of the wearable, I forgot about the wearable. Feedback then came as a surprise, but not an unpleasant surprise.
Socially awkward when being around people that do not know about the project.

The wearable including the bag with electronics is quite big and a bit clumsy.
When sitting for a long time, the feedback and its timing is still fine, but after walking for a while and sitting again, the feedback and its timing is no longer correct.
Sensor at the tail moves very easily
Tail feels as a lot of stuff in the pants, feels uncomfortable.
Constant feedback while cycling, but this can also be because the sensors had moved during walking (down the stairs) to the bike.

---

24 June 2018 *10.30 am - 12.00 pm*
Worn: *Over singlet underneath a jumper, tail in skinny jeans*
Feedback time threshold: *Okay*

Vibrations make a lot of noise when positioned in a silent environment, could be socially awkward in particular situations such as a library.
Can not sit relaxed in on a couch without receiving haptic feedback.
Feeling socially awkward because of all the wires.

This wearable is mainly to test if all the researched placements work. So, to see if the accelerometers can really measure posture when they are implemented in a wearable. If the haptic feedback is really perceived as pleasant and non-disruptive. And whether or not it is feasible all together. Therefore, there is chosen to only shortly test wearable one, so that a longer test period can be executed with wearable two. Next to that, was wearable one quite big while it contains an external bag to hold all the electronics, which makes it very clumsy to work with, and decreases its wearability.

IV.1.3 Recommendations for next wearable

- Less vibrational patterns per time that haptic feedback is applied
- Better cable management:
  - Unable wires to pop out of the breadboard and Arduino
  - Tuck away the cables so that they do not come from underneath the upper body garment
  - Weave the wires along the sides of the vibration dispersing felt

  - Make it possible for the wearer to see if the wearable is still working.

- Felt and wires should not be applied on the skin
- Isolate the accelerometers so that no short circuit can be made and so that they can be properly attached to the wearable
- Change the design of the wearable so that the tail part cannot move and does not feel as bulky in the trousers.
- Decrease the noise of the vibration motors

IV.2 Wearable 2

IV.2.1 Protocol for testing wearable 2

Protocol:

1. Put on the wearable
2. Connect the wearable to the powerbank
3. Calibrate
4. Check if the program works: take on a poor posture for approximately ten seconds
5. Check if the program works approximately each 30 minutes, see step 4
6. Answer the questions, see questions
7. Write down the observations

Questions:

1. How is the wearable worn, with respect to underneath/over clothing?
2. Is the feedback time threshold sufficient?
3. How many feedback patterns are applied with each haptic feedback round, and is this amount desirable?

IV.2.2 Log

While wearing the second wearable, a log is kept, here the questions of the protocol are answered, and all thoughts & opinions about the wearable are depicted.

27 June 2018 *11.15 am - 05.00 pm*
Worn: *Wearable under over sized shirt & skinny jeans*
Feedback time threshold: *Okay*
Number of feedback patterns: *3 times, too much*

Except for the Arduino that is clearly felt on the back, wearable two is very comfortable with respect to wearable one. It is easily forgotten that a wearable is worn.
Because the felt is not pressed against the back by fabric, feedback is not really intense felt when sitting up straight, also not really necessary except for the calibration period.
When you change your posture from poor to correct while receiving feedback, the second and especially third pattern are not really felt, therefore, one or two feedback patterns would also be sufficient.
Wearable two stay good in place, after standing and walking it still gives at the correct time and way feedback.
It does not recognize slight slouching.
No feedback during cycling, which is good.

---

27 June 2018 *07.30 pm - 10.15 pm*
Worn: *Wearable under over sized shirt & skinny jeans*
Feedback time threshold: *Okay*
Number of feedback patterns: *3 times, too much*

Accelerometer sticks in buttock, can be fixed by slightly shifting the lower part of the wearable.
It recognizes primarily bad slouch postures.
Arduino is at the hight of the waistband of a high waisted jeans.
The haptic feedback is slightly disruptive when you totally forget about the wearable, but it is not so disruptive that you are completely distracted from the work you are doing.

It is hard to attain a correct posture at the end of the evening, especially when you've already did it for the entire day.

---

28 June 2018 *09.00 am - 04.30 pm*

Worn: *Wearable under over sized shirt & skinny jeans*

Feedback time threshold: *Sometimes feedback was expected but not received*

Number of feedback patterns: *3 times, too much*

Wearable is slightly tight in the crotch when you stand up straight.

Arduino is a bit bulky, you feel it when you sit against the backrest of a chair.

It does not see each slouch posture.

Personally, at the end of the afternoon it was hard to sit up straight, and than feedback is perceived as a bit annoying while you're tired of sitting up straight.

Maybe decrease the posture threshold, so that more slouch postures are recognized as slouch postures.

---

29 June 2018 *11.00 am - 04.00 pm*

Worn: *Wearable under semi-tight shirt & skinny jeans*

Feedback time threshold: *Threshold should be smaller*

Number of feedback patterns: *2 times, good!*

Threshold for the feedback smaller?

Wearable quite hot to wear on warm days.

2 Feedback patterns are way better, while the first one reminds you of your posture and the second one is motivational push and support for the change of posture.

---

30 June 2018 *10.15 am - 03.45 pm*

Worn: *Wearable under semi-tight shirt & skinny shorts*

Feedback time threshold: *Threshold should be smaller*

Number of feedback patterns: *2 times, good!*

A poor posture is more easily attained when you are sketching on a piece of paper, or if you are doing things very concentrated in photoshop, than when you are typing a report. It is then annoying to receive feedback.
It is hard to attain a correct posture on a chair with a bad backrest. It is almost impossible to prevent feedback when you are seated on a couch.
Battery might be a bit smaller, while it is more than half full, while it is used for all wearable testings until now. So when a battery is used of for example 5000 mAh, instead of 10000 mAh, its size might also be decreased and than it might be possible to implement it in the wearable so nothing is external anymore.

---

30 June 2018 *03.45 am - 04.30 pm*
Worn: *Wearable under semi-tight shirt & skinny shorts*
Feedback time threshold: *Good!*
Number of feedback patterns: *2 times, okay*

Feedback time is adapted, the threshold is now (min. + max.)*0.4. This is a better threshold. I become very tired from attaining a proper posture and working at the same time for the whole day.

---

1 July 2018 *02.45 pm - 05.15 pm*
Worn: *Wearable under skinny shorts*
Feedback time threshold: *Good!*
Number of feedback patterns: *2 times, good*

The feedback timing is now way better, it sees slight slouch, but is not so fast that it is annoying.
The wearable works fine without giving feedback, when other actions are executed than seated work, such as doing the laundry or tying shoelaces.

IV.2.3 Recommendations for next wearable

- Decrease the size of the accelerometers or at least make sure they cannot point in the skin of the user. This can be done by rounding off the corners or putting the accelerometers in silicone
- Use another microcontroller, a smaller one without headers will decrease the size of the microcontroller-perfboard unit
- Put the microcontroller higher on the wearable and at the front side instead of the back (test the height with the use of highwaisted jeans)
- Make an option in the system that threshold can easily be adapted (for the weariness at the end of the day)
- Plait the wires inside the vibration dispersing material instead on the outside
- Solder together the ground wires of the three vibration motors per VDM, in this way only one ground wire has to go from each VDM to the Arduino (less wires in wearable)
- Make use of a smaller battery so that it can also be implemented *in* the wearable
- When using a body again, use one with a longer back so that it is not tight in the crotch
- Try making a wearable that has less skin surface contact
- Make the intensity of the vibration motors in the first pattern less intense than the second, so that the haptic feedback is more intuitive

Appendix V

Hardware setup prototypes

Both prototype wearables measure posture and apply haptic feedback on this if the posture is not sufficiently correct. For this measurement and appliance of feedback, electronics are used. This appendix depicts the hardware specifications and setups of both prototype wearables in tables and figures.

	Name	Amount	Dimensions
Microcontroller	Arduino Uno	1x	68.6 mm x 53.3 mm x 10 mm
Sensors	GY521 MPU6050	2x	20 mm x 16 mm x 3 mm
Actuators	Vibrating motor	6x	d: 10 mm h: 2.65 mm
Wire dividers	Breadboard	1x	85 mm x 55 mm x 10 mm
Power source	Powerbank 10000 mAh	1x	60 mm x 91 mm x 22.5 mm

Table V.1: Electronics specifications wearable one

	Name	Amount	Dimensions
Microcontroller	Arduino Uno	1x	68.6 mm x 53.3 mm x 10 mm
Sensors	GY521 MPU6050	2x	20 mm x 16 mm x 3 mm
Actuators	Vibrating motor	6x	d: 10 mm h: 2.65 mm
Wire dividers	Perfboard	1x	60 mm x 58 mm x 1.5 mm
Power source	Powerbank 10000 mAh	1x	60 mm x 91 mm x 22.5 mm

Table V.2: Electronics specifications wearable two

Arduino pins	Usage
5V	VCC Accelerometer 1 & 2
GND	GND Accelerometer 1 & 2 and GND vibration motor 1-6
A4	SDA Accelerometer 1 & 2
A5	SCL Accelerometer 1 & 2
D3	left lower vibration motor
D5	left middle vibration motor
D6	left upper vibration motor
D9	right lower vibration motor
D10	right middle vibration motor
D11	right upper vibration motor
D12	AD0 Accelerometer 1
D13	AD0 Accelerometer 2

Table V.3: Arduino pin usage wearable one & two

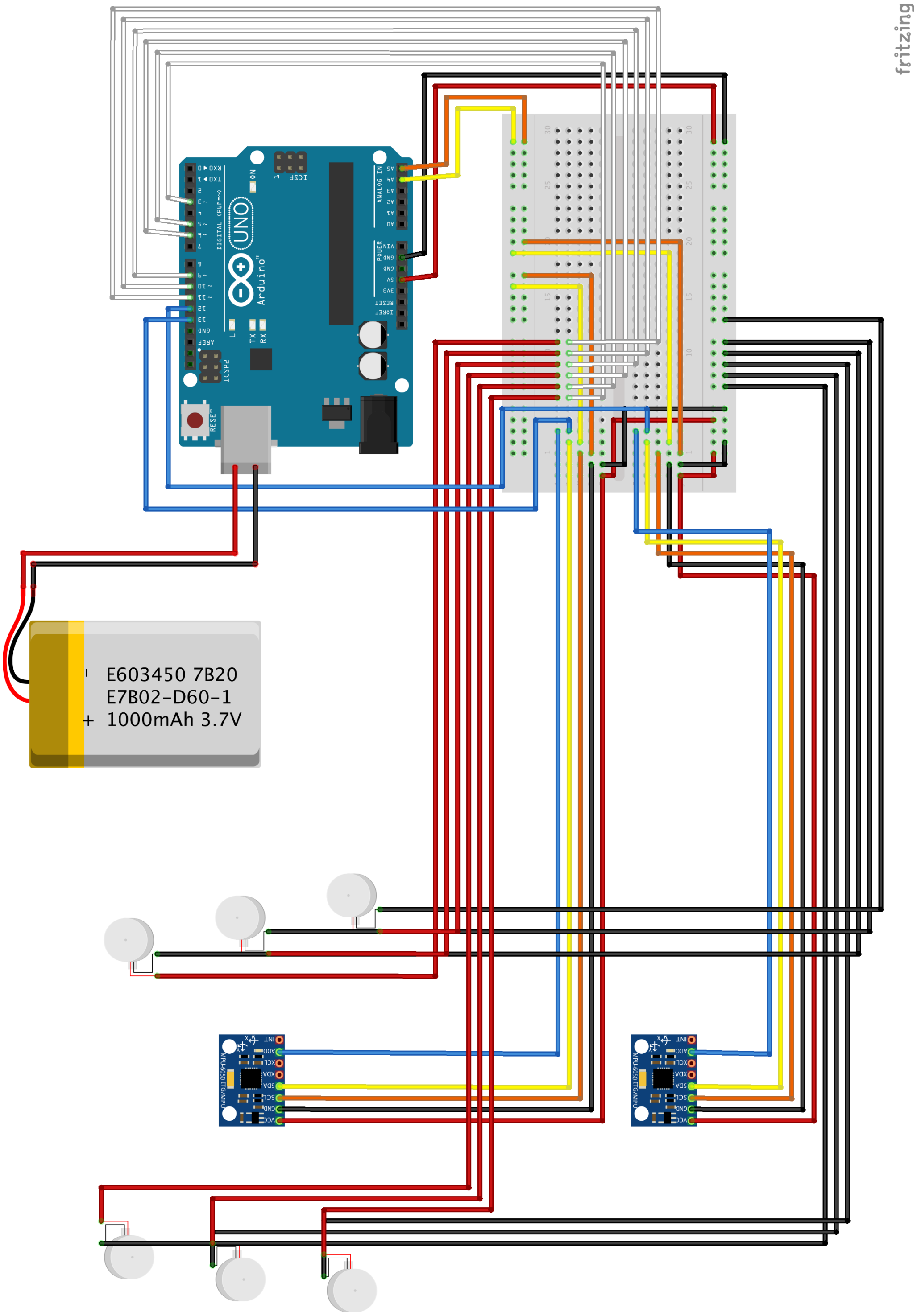


Figure V.1: Hardware setup wearable one

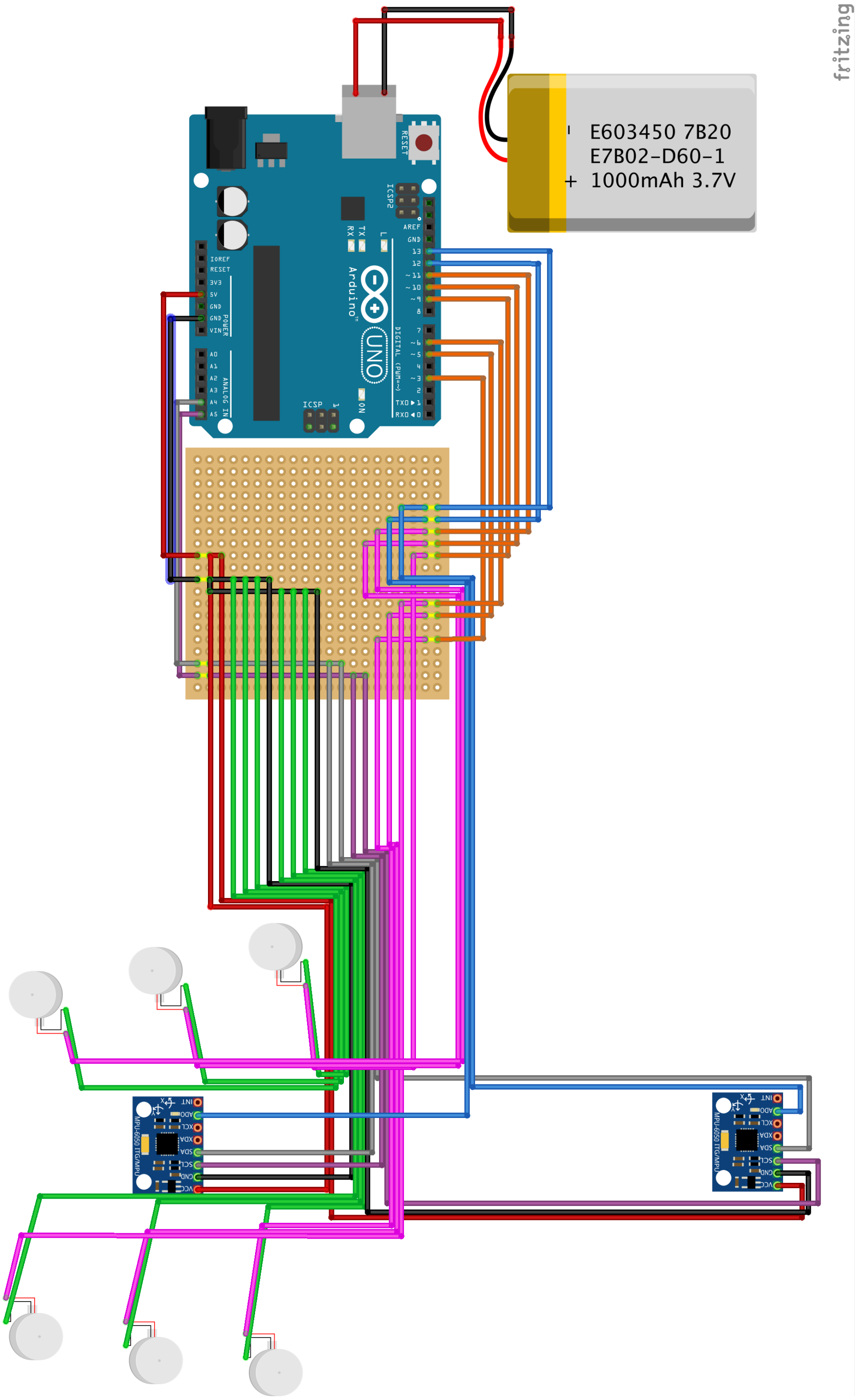


Figure V.2: Hardware setup wearable two

Appendix VI

Software

VI.1 Arduino code

```
// Program for a posture correcting wearable using haptic feedback
// Included parts of RoboticTextilesHWv1.0 by Angelika Mader
// Hardware: Arduino Uno, 2 GY521 MPU-6050, 6 vibration motors

// Floor Visser June 2018

#include<Wire.h>
int16_t AcX, AcY, AcZ, TmP, GyX, GyY, GyZ;

const int MPU_addr = 0x68;          // I2C address of the first MPU-6050
const int numberOfSamples = 60;     // to create an average of the accelerometer data
int32_t delta;

const int sampleFrequency = 60;     // samples per second

const int AD00 = 12;                // mpu above pelvis
const int AD01 = 13;                // mpu halfway the pelvis

const int vibrationPinL1 = 3;       // left lower vibration motor
const int vibrationPinL2 = 5;       // left middle vibration motor
const int vibrationPinL3 = 6;       // left upper vibration motor
const int vibrationPinR1 = 9;       // right lower vibration motor
const int vibrationPinR2 = 10;      // right middle vibration motor
const int vibrationPinR3 = 11;      // right upper vibration motor

const int durationCalibration = 10000;
int timerCalibration = 10000;

int32_t minCorrectPosture = 0;
int32_t maxSlouchPosture = 0;
```

```
int32_t postureThreshold = 0;

enum class ProgramState {
  Initialization,
  Calibration,
  Working,
  PoorPostureSignalization,
};

ProgramState phase = ProgramState::Initialization;

void setup() {
  digitalWrite(SDA, HIGH);
  digitalWrite(SCL, HIGH);

  pinMode(AD00, OUTPUT);
  pinMode(AD01, OUTPUT);

  pinMode(vibrationPinL1, OUTPUT);
  pinMode(vibrationPinL2, OUTPUT);
  pinMode(vibrationPinL3, OUTPUT);
  pinMode(vibrationPinR1, OUTPUT);
  pinMode(vibrationPinR2, OUTPUT);
  pinMode(vibrationPinR3, OUTPUT);

  Wire.begin();

  initMpu(0);
  initMpu(1);

  Serial.begin(9600);
  Serial.println("Starting posture correcting wearable");

  timerCalibration = millis();
}

void loop() {
  switch (phase) {
    case ProgramState::Initialization: {
        Serial.println(" phase 0: Initialization");

        patternVibration(1);

        minCorrectPosture = 11000;
        maxSlouchPosture = 0;

        timerCalibration = millis();

        phase = ProgramState::Calibration;
        break;
```

```
    }

  case ProgramState::Calibration: {
      Serial.println(" phase 1: Calibration");

      ///// Sitting up straight calibration /////

      while (millis() - timerCalibration < durationCalibration) {
        delta = getDelta(50);
        if (delta < minCorrectPosture) minCorrectPosture = delta;
        Serial.print("minCorrectPosture = "); Serial.println(minCorrectPosture);
      }
      spotVibration(2);
      timerCalibration = millis();

      ///// Slouching calibration /////

      while (millis() - timerCalibration < durationCalibration) {
        delta = getDelta(50);
        if (delta > maxSlouchPosture) maxSlouchPosture = delta;
        Serial.print("maxSlouchPosture = "); Serial.println(maxSlouchPosture);
      }

      patternVibration(3);
      postureThreshold = ((minCorrectPosture + maxSlouchPosture) * 0.4);
      delay(500);

      phase = ProgramState::Working;
      break;
    }

  case ProgramState::Working: {
      Serial.println(" phase 2: Working");

      delta = getDelta(sampleFrequency);

      if (poorPosture()) {
        for (int f = 0; f < 150; f++) {
          if (delta > postureThreshold) {
            Serial.println("Poor posture");
          } else {
            break;
          }
        }
        phase = ProgramState::PoorPostureSignalization;
      }
      break;
```

```
      }

    case ProgramState::PoorPostureSignalization: {
        Serial.println(" phase 3: Poor posture signalization");

        delta = getDelta(sampleFrequency);

        if (poorPosture()) {
          Serial.println("   !!  Poor Posture !!   ");
          patternVibration(2);
          phase = ProgramState::Working;
        }

        if (!poorPosture()) {
          phase = ProgramState::Working;
        }
        break;
      }
  }
}

///// Accelerometers /////

void initMpu(int mpuIndex) { // NOTE: also wakes MPU
  writeAcc(mpuIndex, 0x6B, 0x1 << 1); // set CLKSEL to 1 (use x-axis gyro reference)
  writeAcc(mpuIndex, 0x1B, 0x0 << 3); // set FS_SEL to 0 (use full scale gyro)
  writeAcc(mpuIndex, 0x1C, 0x0 << 3); // set AFS_SEL to 0 (use full scale accel)
}

void resetMpu(int mpuIndex) {
  Serial.println("Resetting mpu...");
  writeAcc(mpuIndex, 0x6B, 0x1 << 7); // set DEVICE_RESET bit of PWR_MGMT_1 register to 1
  delay(100);
  writeAcc(mpuIndex, 0x68, 0x1 | 0x2 | 0x4); // set GYRO_RESET, ACCEL_RESET & TEMP_RESET bits of SIGNAL_PATH_RESET register to 1
  delay(100);
  initMpu(mpuIndex);
}

void selectMpu(int mpuIndex) {
  if (mpuIndex == 0) {
    PORTB |= _BV(PB5);     //turn digital pin 13 high
    PORTB &= ~_BV(PB4);    //turn digital pin 12 low
  }
  else if (mpuIndex == 1) {
```

```
    PORTB |= _BV(PB4);     //turn digital pin 12 high
    PORTB &= ~_BV(PB5);    //turn digital pin 13 low
  }
}

void writeAcc(int mpuIndex, int addr, int value) {
  selectMpu(mpuIndex);

  Wire.beginTransmission(MPU_addr);
  Wire.write(addr);          // PWR_MGMT_1 register
  Wire.write(value);         // set to zero to wake up the MPU-6050
  Wire.endTransmission(true);
}

int16_t readAcc(int mpuIndex) {
  selectMpu(mpuIndex);

  Wire.beginTransmission(MPU_addr);
  Wire.write(0x3B);      // starting with register 0x3B (ACCEL_XOUT_H)
  Wire.endTransmission(false);

  Wire.requestFrom(MPU_addr, 14, true);

  auto const readShort = [] () {
    return Wire.read() << 8 | Wire.read();
  };

  AcX = readShort();
  return AcX;
}

int32_t getDelta(int sampleFrequency) {
  int32_t average0, average1;

  average0 = 0;
  average1 = 0;

  for (int i = 0; i < numberOfSamples; i++)  {
    average0 += (int32_t) readAcc(0);
    average1 += (int32_t) readAcc(1);
    delay(1000 / sampleFrequency);
  }

  if ((average0 == 0) || (average1 == 0)) {
    resetMpu(0);
    resetMpu(1);
  }

  average0 = average0 / numberOfSamples;
```

```
  average1 = average1 / numberOfSamples;
  delta = (average0 - average1);

  Serial.print("Ac0␣=␣"); Serial.print(average0);
  Serial.print("␣Ac1␣=␣"); Serial.print(average1);
  Serial.print("␣Posture␣threshold␣=␣"); Serial.print(
     postureThreshold);
  Serial.print("␣Delta␣=␣"); Serial.println(delta);

  if ((average0 == -1) || (average1 == -1)) {
    resetMpu(0);
    resetMpu(1);
  }
  return delta;
}

///// Posture detection /////

boolean poorPosture() {
  return (delta > postureThreshold);
}

///// Vibration /////

// All vibration motors vibrate in an upwards pattern, both VDM's
    at the same time
void patternVibration(int times) {
  for (int i = 0; i < times; i++) {

    digitalWrite(vibrationPinL1, HIGH);
    digitalWrite(vibrationPinR1, HIGH);
    delay(250);
    digitalWrite(vibrationPinL1, LOW);
    digitalWrite(vibrationPinR1, LOW);
    delay(0);
    digitalWrite(vibrationPinL2, HIGH);
    digitalWrite(vibrationPinR2, HIGH);
    delay(250);
    digitalWrite(vibrationPinL2, LOW);
    digitalWrite(vibrationPinR2, LOW);
    delay(0);
    digitalWrite(vibrationPinL3, HIGH);
    digitalWrite(vibrationPinR3, HIGH);
    delay(400);
    digitalWrite(vibrationPinL3, LOW);
    digitalWrite(vibrationPinR3, LOW);
    delay(400);
  }
}
```

```
// Middle vibration motor of both VDM vibrate once
void spotVibration(int times) {
  for (int i = 0; i < times; i++) {
    digitalWrite(vibrationPinL2, HIGH);
    digitalWrite(vibrationPinR2, HIGH);
    delay(1000);
    digitalWrite(vibrationPinL2, LOW);
    digitalWrite(vibrationPinR2, LOW);
    delay(500);
  }
}
```

VI.2 Block schema

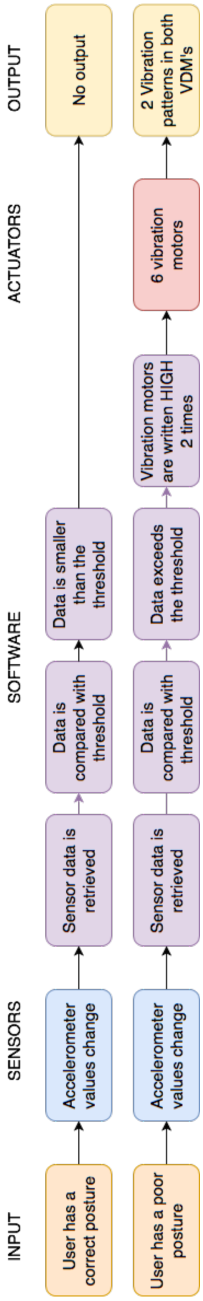


Figure VI.1: Block schema of possible interactions with the system

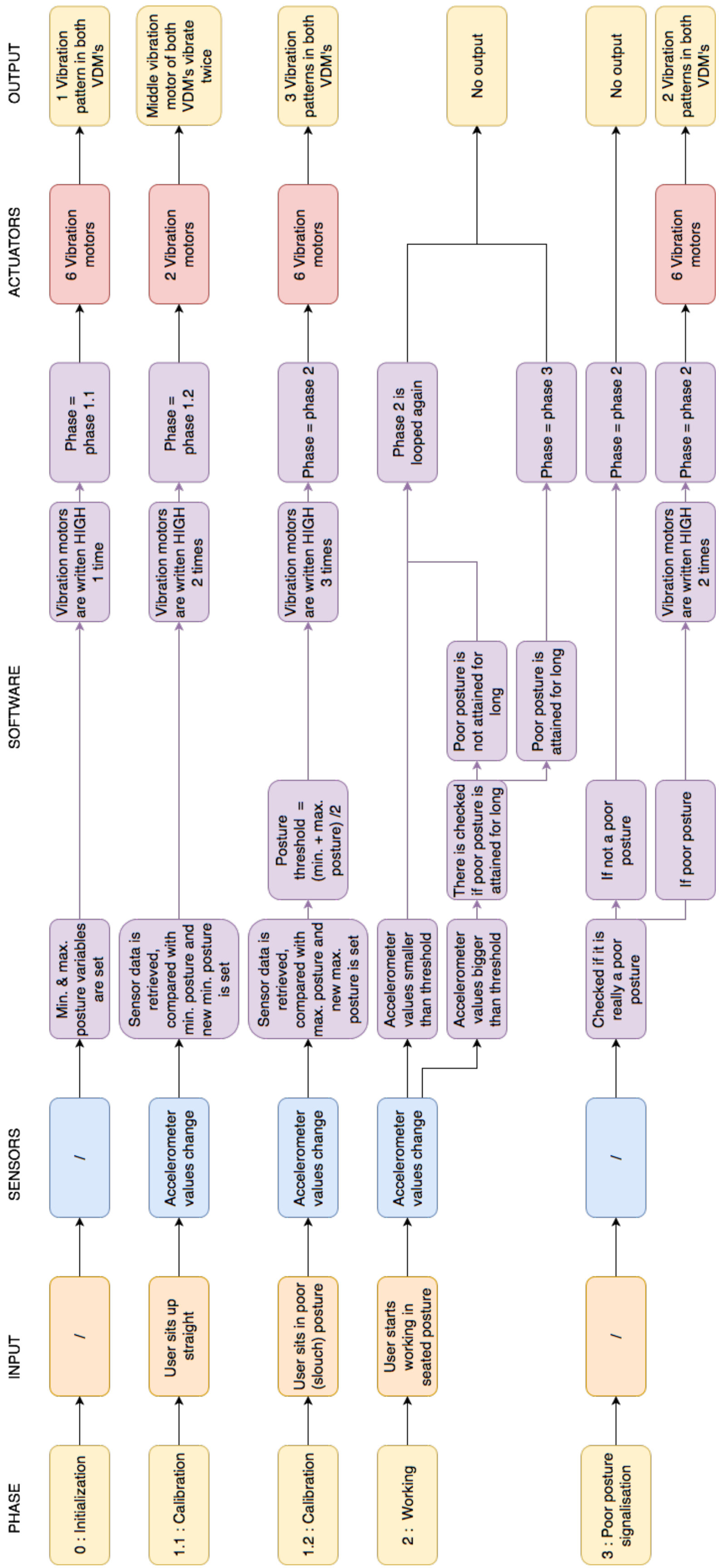


Figure VI.2: Block schema of possible interactions with the system regarding the code

Appendix VII

Reflection report

VII.1 Introduction

VII.1.1 Problem statement

Technology is a large part of current society and people their lives. Due to all the electronic devices such as smartphones, tablets and laptops, people are busier than ever. Because of this constant stream of information and to-dos, simple actions such as keeping a correct posture are completely forgotten. It is only when the negative effects of this incorrect posture are shown, in the form of a painful back, that people start to think about their posture. In order to prevent this painful back, haptic feedback in wearable technology is going to be used to correct the seated posture of the user. Haptic feedback is computer controlled feedback that is perceived by the human body as the feeling of touch [1]. This feedback and its effect is attained by a device that exchanges forces from a computer to the user [2]. A big advantage of haptic feedback in wearable technology is its low cognitive load. The feedback can be applied at the spot where work needs to be done in order to alter the posture of the human body.

For this graduation project, a wearable is equipped with sensors and vibrating actuators. These sensors will measure the user its posture, the measured data will be compared with the calibrated data, and dependent on the deviation, haptic feedback will be applied. The haptic feedback will not serve as a reminder, on the contrary, it has to disturb the user as little as possible. To do this, the feedback will be applied at the body as a support for the user to intuitively change its posture. Intuitive placement of haptic feedback is obtained by placing the vibrational actuators near the spot where motor actions in the body have to be executed [3]. In this project, feedback will thus be given to the muscles that correct the seated posture.

The project uses an autoethnographic design method approach. This means that the design is set up on the base of the researcher & designer. The prototype does not have to be tested on multiple people from an user group, because there is no user group besides the designer & researcher herself. However, findings from an autoethnographics design point of view, could be used in further research. There can be tested whether or not these findings also apply to a certain user group. For this report, there will be assumed that the prototype will become a product that is also used by other people than the researcher & designer.

Placing vibrational haptic feedback, or wearable technology in general, on the body brings along some ethical questions. Especially since the wearable is placed at the lower back and upper part of the bum. Just as the placement of wearable technology, another ethically questionable part of this project is the autoethnographic design method, since this requires some objective skilled research. That is why this reflection report will evaluate the placement of haptic feedback in wearable technology and the manner in which the autoetnograhpic design method is applied in this project.

VII.1.2 Research questions

For this reflection report of haptic feedback in wearable technology from an autoethnographic poinyt of view, the research question is formulated as: *Is haptic feedback in a posture correcting wearable that is designed from an autoethnographic design point of view, ethically appropriate?* To support this research question, several subquestions are composed:

1. Which places on the body are ethically appropriate for the placement of wearable technology?

2. Which places on the body are ethically appropriate to give vibrational feedback to?

3. How biased is the research in this project with its autoethnographic design method?

4. To what extend is the researcher & designer skilled enough on the topics to make a product that compels users to take on a correct posture?

VII.2 Context

VII.2.1 Placement wearable

In this project a wearable is designed that detects the (in)correct posture of the human body. When this posture is not sufficiently correct, vibrational haptic feedback is applied to support the user its posture. A wearable is a device that is worn on the human body [35] and for this wearable there are multiple requirements that have to be satisfied:

- It should be as small as possible
- It should be as little obtrusive as possible
- It should work intuitive

In other words, the wearable should have a high (dynamic) wearability: proper interaction between the human body and the wearable (in movement) [35].

Of course the wearable raises some ethical questions, while it is designed for around the body at the height of the lower back and the upper part of the bum. In this section wearable technology will be addressed as well as vibrational haptic feedback, both these subjects are dealt with, with respect to the placement and the (social) acceptability it.

Wearable technology

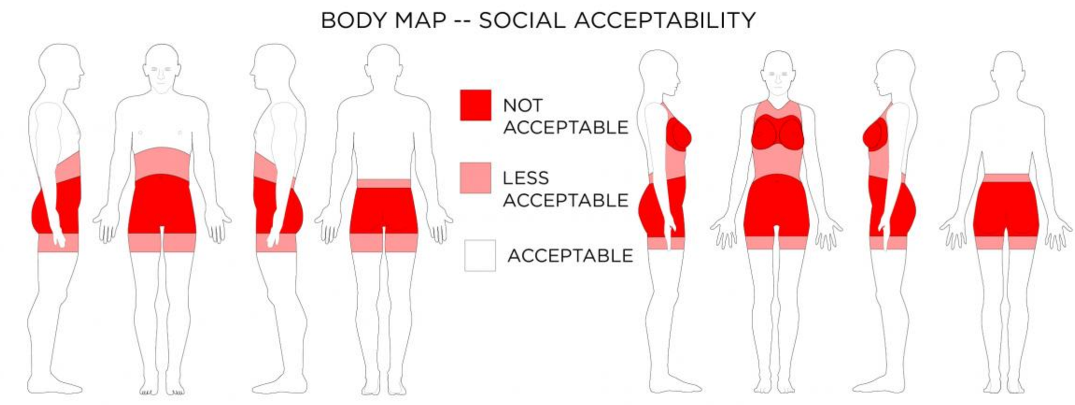


Figure VII.1: Social Acceptability, image by Clint Zeagler

Wearable technology gives the possibility to extend the retrieving and processing of information from the static environment of computers, to the dynamic environment of technology that can be taken everywhere, while it is attached to the body. According to Zeagler [36], the placement of the wearable technology, irrespective of what type of technology, can extremely affect the way that the wearable is socially accepted. Gemperle et. al. [35] agree on this and state that it is important to work within the appropriate areas of the dynamic human body. Profita et. al. [37] agree and state that the adoption of wearable technology is subjected to societal conventions. As shown in figure VII.1, Zeagler [36] explains that places that are associated with sex are the least acceptable for wearable technology. Not only the placement of the wearable is important for the adoption, also its emanation. When the wearable its usage is supportive technology, and especially when it has to be inconspicuous, it should not have a medical emanation. Zeagler [36] also states that the wearable should not disturb or obstruct the user. In figure VII.2 he [36] shows that there are several places that have a certain level of motion impedance. Gemperle et. al. [35] agree on this and state that placing a wearable on the following places, is least obtrusive: (a) collar area, (b) rear of the upper arm, (c) forearm, (d) rear, side & front ribcage, (e) waist & hips, (f) thigh, (g) shin, and (h) top of the foot. This corresponds with the areas that are shown in figure VII.2.

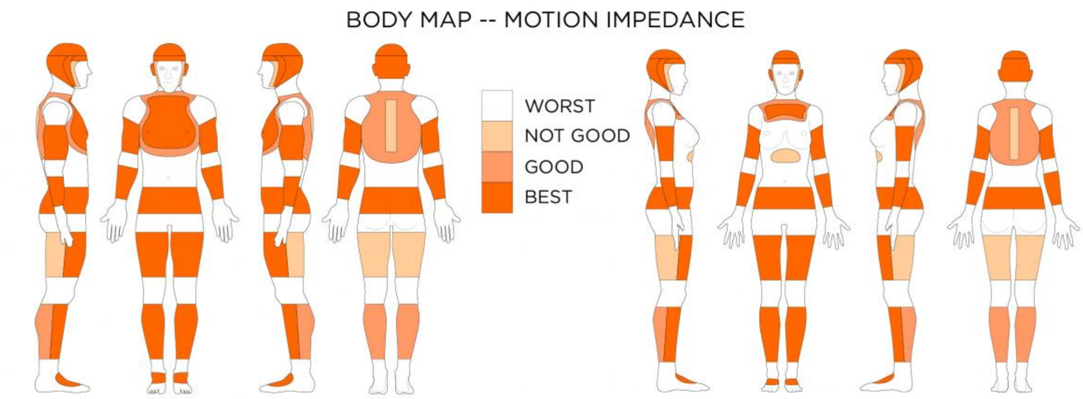


Figure VII.2: Motion Impedance, image by Clint Zeagler

When looking at motion impedance, the wearable of this project will not obstruct the user, according to the theories of Zeagler [36] and Gemperle et. al. [35]. This is because the wearable covers the lower part of the back and the upper part of the bum. As is shown in figure VII.2, are those places low in motion impedance. However, those placements do cause a problem in the social acceptability part of the wearable. It lies, as depicted in figure VII.1, exactly there on the body where it is socially inacceptable to place wearable technology.

In order to decide whether or not the social acceptability factor is too big, it might be convenient if there is explained why this placement of the wearable is chosen. A poor posture starts at the pelvis, it tilts backwards, by which the lower part of the spine also tilts backwards, this causes a shift in the centre of gravity of the body. To prevent the body from falling backwards, the upper part of the spine compensates. The poor posture is completed when the chin is extended forwards, this enables the user to look forward again [20]. To measure this posture, two sensors are used. Multiple experiments have been executed with the placement of the sensors. The result of these experiments was that the posture of the human body is best read when the sensors are placed just above and halfway the pelvis.

One of the requirements that need to be satisfied is that the wearable should be as little obtrusive for the user as possible. Several theories and experiments have shown that the obtrusiveness of the haptic feedback depends on its placement. Shull and Damian [12] have discovered that in order to guide the human body, the vibrational feedback should be placed near body joints. And Zheng and Morrell [3] have stated that in order to let the feedback feel intuitive, it should be placed near the spot where motor actions have to be executed, such as the tightening of a muscle. Furthermore, experiments that have been executed for this project have shown that vibrational feedback on the bone is way more obtrusive than vibrational feedback on muscles. Several spots on the back are tested on most effective and least obtrusive. Feedback to the big muscles at both sides of the spine just above the pelvis, have shown to be most effective and least obtrusive, which complies with Shull and Damian [12] and Zheng and Morrell [3] their theories.

When taking the requirements into account, looking at what a poor posture is and how it is formed, following the theory of intuitive and effective feedback, and taking into account that nobody is forcing the user to wear the wearable, there can be concluded that the social unacceptability of the wearable does not weigh up against the effectiveness of the wearable on its current position.

Vibrational haptic feedback

The haptic feedback that is applied to correct someone's posture, is vibrational feedback. This vibrational feedback is applied on the big muscles at both sides of the spine. Three vibration motors make an upwards pattern to stimulate a change of posture. The haptic feedback is positioned on these muscles while receiving a vibration on a muscle is perceived as a pleasant feeling. This is in contrast with vibrations on the bone, which can be felt through large part of the skeleton and genuinely feels unpleasant. There is chosen to use pleasant haptic feedback rather than unpleasant. This is while changing a posture is something that requires a lot of intrinsic motivation, and wearing the wearable is something that should not be forced upon someone. Therefore, a pleasant experience would be more effective on the long run, so that the user sees the wearable as an aid rather than a punishment device. Next to the association of aid and punishment, experiments executed for this project have shown that there are multiple places on the bone that create more than just unpleasantness. These places, indicated in figure VII.3, create: (a.) headaches, (b.) unexpected pain in the legs, or (c.) the need to go to the bathroom. These big inconveniences make placing vibrational feedback on the bone unethical and motivate the choice for the current placement of the haptic feedback.

Figure VII.3: Vibration feedback on the bone

VII.2.2 Autoethnographic design method

The autoethnographic design method is a way of designing based on research done on the researcher herself. This research is executed via studies that pursue traditional ethnographic research guidelines, but take place within the researchers' own environment. This has the advantage that small selectively focused research cycles can be executed [5]. Another advantage, with regard to wearables, is for example that clothing sizes do not have to be taken into account.

A traditional ethnographic researcher tries, with her research, to become an insider in the research topic. An autoethnographic researcher does not have to try to become this, while she already is the insider of the topic, this is because the context is his own. In this way it is possible for individuals, that would normally be left out of ethnographic research, to be researched [6]. That autoethnographic researchers find themselves in the center of the focus, becomes clear when looking at the observation element of research. Observation of participants is one of the most important aspects of research, no matter of its kind [5]. With ethnographic research these observations can become an obstacle, while permission needs to be gained by the observer for the researcher to become a participant in their world. Autoethnographic researchers don't have this obstacle while they are already fully immersed in the situation of the research its focus [5].

Autoethnography seems so convenient, but there are also downsides to this design method. Parks [[38] as cited by [5]] has written down the most common pitfalls of autoethnography that can lead to research results that are not on an academic correct level. Pitfalls are that the researcher needs to be able to not only get across the emotional side, but should also provide a deeper level of reflection and analytic scholarship. Autoethnography should be chosen as a design method with a sincere reason, not to justify certain actions. While this way of doing research can become very personal, it is important that the researcher keeps track of the difference between personal experience and scientific correct data. Also emotionally related is that the researcher needs to be able to defend against reasoned critique while still relaying on the knowledge that is gained by the autoethnographic research. When bringing these pitfalls back to two concrete sections, there is the question whether or not the analytic scholarship is biased by the influence of the researcher. And the second section is the ability of the researcher, is she capable enough to do proper research into an unfamiliar field. A critical review on these two aspects of autoethnography with respect to this project, will be depicted in the following two subsections.

Bias

The challenge of participant observation in autoethnographic research lies, according to Duncan [5], in mastering of the art of self reflection. For this project there are several researches that have to be executed. Most of them can easily be executed objective, but will shortly be mentioned.

The first one is the State of the Art research, this research contains a literature review of academic papers, interviews with professionals and reviews of similar products. Autoethnographic research is very personal, which can easily influence the objectivity of the researcher in selecting papers, questions to include in the literature review and interview, or influence the opinion of the researcher on the similar products. However, in this reasoning there has to be taken into account that the research is academic and that the researcher should thus execute objective research in order to obtain valid results. Since an autoethnographic researcher wants, just as a regular ethnographic researcher, to get valid insights in a topic, objective research is crucial.

The second research item is sensor placement. With this research there is inquired where and how many sensors are required to measure a correct posture. This is done by placing multiple (different) sensors on the body and saving the retrieved data. The data from all the experiments are compared, and the sensors and their placement with the most accurate outcome is chosen. This research part is supported by data and thus hard to be biased.

The third research is the haptic feedback part. During this research, several experiments are done to get insight in where and what kind of feedback should be placed. There is looked into the intensity of the vibrations, how long, how often, if they should be at one spot or multiple and if they should be in a pattern or not. All these experiments will be executed on the researcher & designer which makes this part of this autoethnographic research highly subjective. The kind of haptic feedback that will eventually be implemented, depends completely on the researcher her preference for type and place of haptic feedback. It is arguable whether or not this is the correct way for making the choice for the haptic feedback. When this research would be a traditional ethnographic research, this would be the moment where a lot of test persons would enter the research. All the experiments would then be executed on the test persons. From all their preferences a statistically grounded choice would be made on what type of haptic feedback there would finally be implemented. However, with this project an autoethnographic design method is pursued and the goals of the project is to make a wearable that corrects the researcher & designer her posture. So with this reasoning, there could be stated that this way of researching is not biased, rather, it is the only way to create a wearable that accomplishes the goal of this project. Next to the fact that this manner of doing research is part of the project, there is also the problem that being aware of the possibility to receive haptic feedback already has effect. Zheng and Morrell [3] have shown that knowing that haptic feedback can be received creates such an awareness that actions, that would be triggered by the haptic feedback, are already executed without the haptic feedback trigger. Which is attaining a correct posture in this case. This awareness problem would also be present with test person and could potentially be even bigger, while they might be tense due to the fact that they are test persons and want to properly engage in the experiments without making mistakes.

The fourth research item is the evaluation of prototype wearables There are prototype wearables developed for this project, these need to be evaluated. However, while the wearables are designed for the body and preference of the researcher & designer, it can only be tested by the researcher herself. To minimize the amount of bias, a log is kept where the researcher drops every opinion, whether it is good or bad. Another way to make this part more objective, is by supporting it with raw data. This is not done for the first wearable, but when carrying out further research with more wearables, this element could be added.

According to Yin [[30] as cited by [5]], autoethnographic research its reliability will increase when a protocol is followed that allows other people to execute the same research. For this project, all the experiments that are executed are documented with a goal, method, pictures, obtained results and a conclusion. This makes it possible for other people to re-execute the experiments, and make together with the other statement in this section, this autoethnographic research as little biased as possible.

Skills

For this project a posture correcting wearable with haptic feedback implemented is developed. This big project can be divided into three main categories: (a.) posture, (b.) wearable technology, and (c.) haptic feedback. The researcher her field of expertise lies, due to her study, mainly in the haptic feedback category. Wearable technology is a combination of electronics and clothing design, from which only the technology part lies withing the researcher her field of expertise. And finally the posture category, this lies in the physiotherapy domain, which does not corresponds with the field of expertise of the researcher. Half of the domains do not lie within the field of the researcher's expertise, which makes it questionable whether or not the researcher is skilled enough to create a wearable that has haptic feedback implemented to properly corrects someone on its posture.

However, there are theories that state that a certain amount of unfamiliarity of the research topic is necessary for good autoethnographic research [[31] as cited in [32]]. Burdell and Swadener [[33] as cited in [32]] also state that unfamiliarity in the research topic leads to a topic of conversation, which often provide extra unexpected information. For the first research stage, the State of the Art, a physiotherapist is interviewed. From this interview, the knowledge of a correct posture and how to attain this, is gained. Based on this interview and some academic literature, the posture category of the project is executed. In order to check if the gained information is properly embedded, the professional opinion of the physiotherapist on the prototype can be asked. As with the physiotherapist, multiple other specialists could be asked to give their professional opinion on a prototype, in order to find out whether or not the unfamiliar domains are correctly implemented.

VII.3 Conclusion

To provide an answer on the big research question *Is haptic feedback in a posture correcting wearable that is designed from an autoethnographic design point of view, ethically appropriate?* the subquestions will first briefly be answered. Starting with the appropriateness of the placement of wearable technology, which completely depends on the context. Correcting your posture requires a lot of intrinsic motivation, which means that the wearable should be worn voluntary. When someone chooses to wear the wearable, places that are first labeled as social inappropriate become less inappropriate. Continuing with inappropriate placement of vibrational feedback, for which an undivided approach can be taken. Placing a vibration motor on the bone is unpleasant and can even lead to pain. Therefore, there can be stated that placing vibration motors on bone that leads to pain is unethical placement.

Autoethnograhpic research always has a certain amount of bias. In this research, the researcher is highly aware of it and methods are applied to decrease the bias. This also applies on the field of expertise part, a rough 50% of the domains lie within the academic field of expertise of the researcher. However, according to several theories, some amount of unfamiliarity is required for autoethnographic research. For autoethnograhpic research there can be generally stated that it is important that experts are involved in the process and that the process can be controlled by someone else than the researcher.

So in order to give an answer on the question *Is haptic feedback in a posture correcting wearable that is designed from an autoethnographic design point of view, ethically appropriate?*. Haptic feedback in wearable technology is in the context of this project ethically appropriate since the wearable is not forced upon someone. Additionally, choices in the design are made so that the wearable is most effect and least obtrusive for the user, which satisfies the requirements as mentioned in section VII.2.1. The autoethnographic part is also ethically appropriate, but the work should be checked by someone that is not involved in the project, in order to keep the outcome as objective as possible.