THE DESIGN OF VIBROTACTILE FEEDBACK TO COACH POSTURE IN INLINE SKATING

FINAL PROJECT

Anouk de Graaf
Interaction Technology

Graduation Committee:
Dr. A.H. Mader
Prof. dr. J.B.F. van Erp
Dr. M. Poel
Dr. D.B.W. Postma
J. Weda Msc.

September 2022

UNIVERSITY OF TWENTE.

Abstract

During inline skating, the skating posture is important to reduce air friction and improve speed. However, it is difficult for trainers to provide real-time feedback to the skaters. Haptic feedback could be a solution. Haptic feedback makes it possible to provide real-time feedback to targeted locations. The aim of this research is to design a wearable which provides real-time haptic feedback based on the posture of the inline skater. During the research, small experiments were done which focused on three aspects of the design of the wearable: (1) posture measurements for inline skating, (2) the vibration motor locations for haptic feedback, and (3) vibrotactile patterns. Based on the results of the experiments a wearable was created which provided feedback to the knee angle of the user and the curvature of the back. An evaluation test was performed with 18 participants. The test showed that the haptic feedback is effective to improve the knee angle of the inline skaters, but not the posture of the back. Therefore, it can be concluded that haptic feedback can be a solution to provide real-time feedback to the users to specific parts of the inline skating posture.

Acknowledgement

This thesis would not have been possible without the help from a number of people. First of all, I would like to thank my supervisors Angelika Mader and Judith Weda for their help throughout the project. Angelika and Judith provided many valuable insights on the haptic feedback and kept me on track with the weekly meetings. I would also like to thank them for their enthusiasm during the project.

Second, I would like to thank the members from my examination committee; Jan van Erp, Mannes Poel and Dees Postma for taking the time to provide feedback on my report and being part of the examination committee.

Third, I would like to thank members and trainers of D.S.V de Skeuvel who helped me throughout the project. I would like to thank them all for taking the time to help me with the research project. Without their help, none of the experiments could have taken place.

Fourth, I would like to thank the residents of Huize Marsupilami. Thank you for keeping up with me for almost five years and providing distractions next to studying. Moreover, thank you for helping in experiments whenever participants were needed.

Fifth, I would like to thank the boys of Ludovicus for supporting me throughout my studies and making my time in Enschede more enjoyable.

Lastly, I would like to thank Bart Schepers. Thank you for your love and support over the last four years.

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Chapter 1

Introduction

According to the KNSB (Koninklijke Nederlandse Schaatsenrijders Bond) in 2020, approximately 406.500 people in the Netherlands practised inline skating at least once a year, of which 71.000 people perform inline skating once a week [1]. Moreover, the sport is a good alternative to ice skating when the ice rinks are closed [2]. Similar to ice skating, inline skating is a sport in which the performance is influenced by strength and technique [3]. During inline skating, the largest friction is air friction. To reduce air friction, skaters should stay in a low position with small knee and trunk angles as shown in Figure 1.1.

Figure 1.1: The inline skating posture.

To keep the skating position for a longer period of time can be challenging. Therefore, a trainer tries to provide feedback on the posture during during a training. Inline skating typically happens on 200 or 400 meter skating rinks, which makes it difficult to give real-time feedback to athletes. Providing feedback during an exercise can be done in two ways. First, the trainer can decide to stand in one spot and yell feedback to the athletes. The downside of this is that intermediate inline skaters can skate at a speed of 20 to 30 kilometres an hour, which means that there is only a short time period to yell the feedback. Second, a trainer can skate behind or next to an athlete and provide feedback during skating. The downside of this method is that a trainer can only skate behind one group at a time, making it difficult to provide feedback to all athletes if the athletes have a different skill level.

Haptic feedback could be a solution to provide real-time feedback to skating athletes. With haptic feedback, tactile sensations such as vibration, temperature and pressure can be applied directly to the skin to provide feedback. Research on haptic feedback in sport for posture improvement looks promising. Haptic feedback during cycling, golf and jump landing technique show that haptic feedback can improve performance [4–6]. However, if the provided haptic feedback is not comfortable, the devices are likely to not be used even if they improve performance [7]. This means that haptic feedback should carefully be designed.

Therefore, the goal of this research is to create a haptic device for inline skating which will help skaters to maintain the low skating position. This leads to the one research question and four sub-questions;

RQ: How to design haptic feedback for coaching posture in inline skating?

SQ1: What is the state-of-the-art of vibrotactile feedback in sports?

SQ2: What defines a correct posture in inline skating?

SQ3: How can the correct posture in inline skating be measured?

SQ4: What parameters influence the design of effective haptic feedback?

In chapter 2, a context analysis is held to get more insights in haptics in sports, the inline skating posture and vibrotactile feedback design. Chapter 3 describes the methods and techniques which are used throughout the research to answer the research question. Chapter 4, 5 and 6 describe experiments focused on posture measurement, placement of vibration motors and the design of vibrotactile patterns. In chapter 7, the development of the wearable is described and in chapter 8, the wearable is evaluated. The report closes with a discussion in chapter 9 and a conclusion in chapter 10.

Chapter 2

Context Analysis

The context analysis is aimed to gain information needed to design a haptic wearable to improve the inline skating posture. The first section focuses on haptics in sport in rehabilitation. Section 2.2 discusses the state-of-the-art of vibrotactile feedback in sports. Section 2.3 discusses sensors which can be used to measure the posture. Section 2.4 and 2.5 describe vibration motors and vibrotactile feedback design. The section ends with a conclusion.

2.1 Haptics in sport and rehabilition

Haptics is derived from the Greek word *haptesthai* and means *related to the sense of touch* [8, p.719]. In pshychology and neurosciense, haptics is the study of human touch in sensing via kinestethic and tactile receptors [8]. Kinesthetic sensations refer to receptors in muscles and tendons which feel the pose of the body, while tactile sensations are caused by outside influences, such as pressure, vibration motors and heating pads [9]. In sports and rehabilitation, haptic strategies can be used to facilitate motor learning [9]. This section explains two haptic strategies which are used in sports and rehabilitation; haptic guidance and tactile feedback.

Haptic guidance According to Sigrist et al. [9] haptic guidance is a term to describe various haptic augmented feedback strategies which guide users through the ideal motion using a haptic interface [9]. Of haptic guidance strategies, position control is the most restrictive. Position control forces the user to do a predefined movement using a robot. An example of haptic position control is seen in Figure 2.1. In this figure, the legs of the user are strapped to the machine, which means that the user has to move in the exact same way as the machine. However, since error drives motor learning, position control is not effective to learn users new movements as the process of motor learning is prolonged by about 15 times if errors are prevented [9]. Nonetheless, position control learning could be effective is in early stages of learning complex motor tasks. [9]

Figure 2.1: Example of position control.

Haptic guidance strategies which are less restrictive provide the user with a certain amount of freedom in terms of position or timing [9]. These types of haptic guidance reduce perceived workload and improve current performance. Haptic guidance allows beginners to learn specific movements in a safe and self-explanatory way. For experts, haptic guidance can be effective in teaching detailed technical aspects [9]. Less restrictive haptic guidance has been applied to rowing [10], golf [11] and tennis [12] (see Figure 2.2). In the tennis example, 6 ropes are connected to a tennis racket. These ropes can be used to move the tennis racket. To assist with movement, the system enforces a stroke trajectory and velocity profile after users started the movement. For timing, the robot starts to enforce correct timing at the start of each stroke. [12]

Figure 2.2: One example how haptic guidance can be applied to tennis. [12]

Tactile displays Tactile displays can be used to provide tactile sensations, such as vibrations, static pressure, skin stretch or friction, to the skin to convey information [13]. According to Choi and Kuchenbecker [13], vibrotactile displays are currently more widespread and better understood than other tactile displays. According to van Erp et al. [14] tactile displays can have three functions in sports; provide tactical information, posture information, and provide a motion coordination pattern [14]. Tactical information can provide an athlete with information on where to look and how to move through a field. Posture information explains how a posture should be corrected and movement coordination combines how to move and when to move to provide information about a complete movement [14].

Haptic guidance is not a suitable method of haptic feedback during inline skating, as inline skating is often performed outside at a high speed. Therefore, tactile feedback is more promising to use during inline skating. Since vibrotactile feedback is better understood and more widely used compared to the other types of tactile feedback, the focus in this research is on vibrotactile feedback. To get an overview on how vibrotactile feedback is applied to sports, a state-of-the-art overview was made.

2.2 State-of-the-art of vibrotactile feedback in sports

Vibrotactile feedback has been applied to many sports, such as cycling [4], golf [5], snowboarding [15], swimming [16], speed skating [17] and more [18]. In the following section, first the state-of-the-art of vibrotactile feedback for posture correction in sports is researched. Second, the use of vibrotactile feedback in skating is investigated.

2.2.1 Vibrotactile feedback for posture correction in sports

Peeters et al. [4] focused on improving the aerodynamic posture during cycling. Vibrotactile feedback was used to remind the cyclist to stay in the aerodynamic posture. The set-up (see Figure 2.3) makes use of a camera, which calculates the projected frontal area of a cyclist. If the projected frontal area exceeds a margin compared to the reference position, a vibration motor placed on the neck of the athlete vibrates to remind the athlete to stay in the aerodynamic position. The study found that without feedback is was more difficult to recapture the aerodynamic reference position compared to with vibrotactile feedback. Moreover, the optimal margin for when feedback should be provided was dependent on participants. For amateurs, it is not recommended to use strict margins, as this causes continuous cues if the reference position cannot be maintained, which was found annoying by the participants. [4]

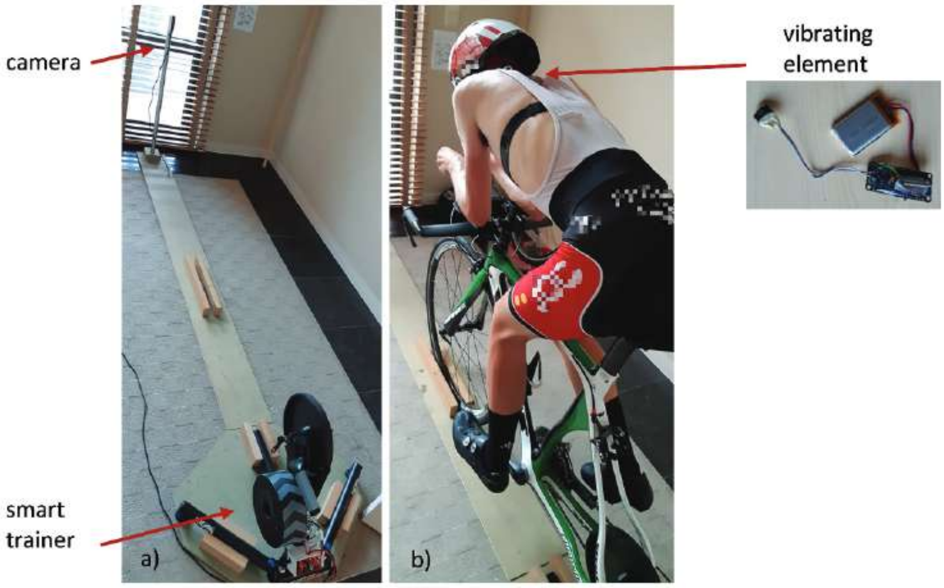

Figure 2.3: The set-up used to provide tactile feedback during cycling. A camera measured the projected frontal area of the cyclist. If this exceeded a margin compared to a reference position, the vibrating element positioned in the neck of the athletes vibrates to remind the athlete to adhere to the aerodynamic reference position. [4]

Next to cycling, vibrotactile feedback has also been applied to mountain biking [19]. Berentsen et al. [19] compared visual and haptic feedback to improve the weight balance during mountain biking. The study tested two types of visual feedback and a vibrotactile belt to provide feedback on the balance. The vibrotactile belt consisted of equally spaced vibration motors which could indicate where a user should shift his weight to. The visual feedback consists of a line of dots, where the colour and position of the dots indicate the direction that the user's weight should shift to. The two types of visual feedback differ from each other with regards to the use of colours and positioning of the light. The feedback design is shown in Figure 2.4. The research shows that the users preferred the vibrotactile feedback and that the feedback improved balance awareness on the mountain bike. The users found vibrotactile feedback more natural and intuitive compared to the visual feedback. The visual feedback was confusing for the participants and sometimes difficult to see due to weather conditions, such as a glare of sunlight. This made the visual feedback higher in cognitive load compared to the vibrotactile feedback. However, the use of the vibrotactile or visual system did not cause significant improvements in balance performance. [19]

Elvitigala et al. [20] have worked on weight balancing during squats. For this, visual and vibrotactile feedback were also compared. The system (Figure 2.5) used sensors in a shoe to measure foot pressure during a squat. The shoe sole was enhanced with vibration motors, which allowed the system to provide feedback based on the weight balance of the user. This was done in two methods; vibration motors in the sole and in the side of the shoe. The visual feedback was provided using a Google Glass or using a monitor, which would show the information on where the centre of pressure was positioned during the squat. The study found that vibrotactile feedback provided on the sole had the best usability, while the vibrotactile feedback provided at the walls of the shoes had the lowest usability. However, there was no significant difference between usability of vibrotactile feedback and visual feedback. The users had a slight preference for visualisation on the monitor compared to other feedback types but the preference for the different feedback system were strongly individual. Qualitative feedback indicated that the Google Glass for visual feedback worked best [20].

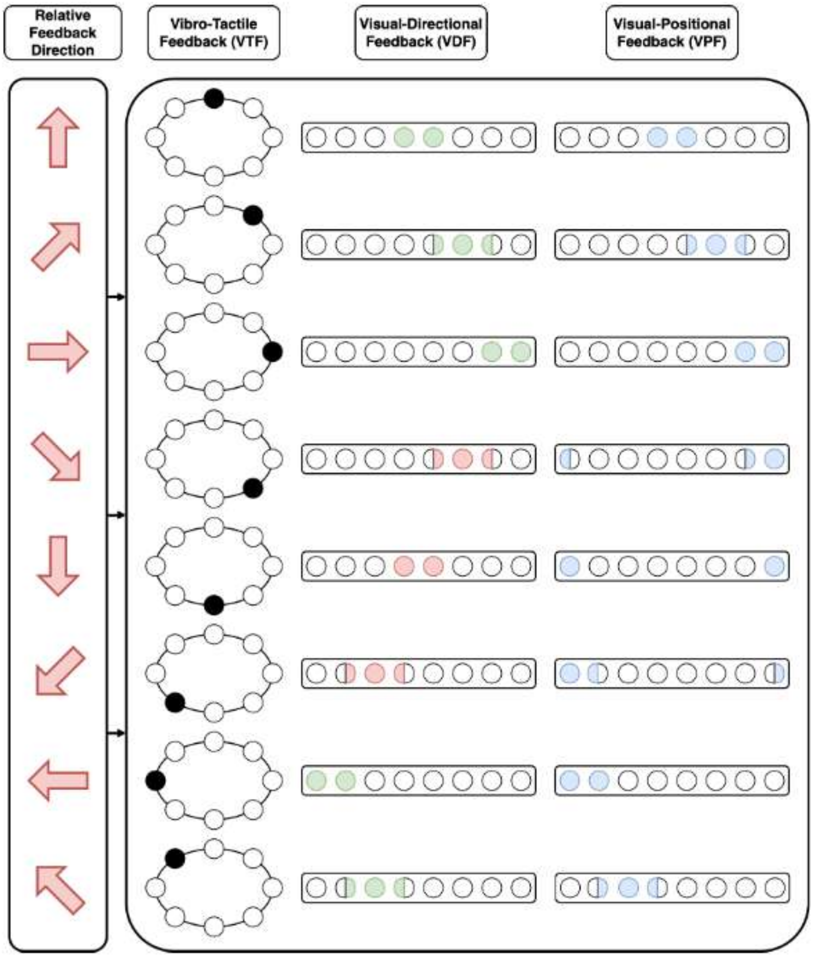

Figure 2.4: The three types of tested feedback during the mountain biking experiments. For vibrotactile feedback, a vibration motor would vibrate to indicate the relative feedback direction. For the visual feedback, the positioning of the lights showed the feedback direction. Visual Directional Feedback made use of two different colours, where green means 'lean forward' and red 'lean backwards'. [19]

Figure 2.5: The designed GymSoles++. The shoe is incorporated with an insole to calculate the body's centre of pressure (CoP) and 8 vibration motors. The vibration motors provide haptic feedback and the Google Glasses provide visual feedback on the CoP of the user. [20]

Spelmezan et al. [15] developed a haptic feedback system to provide real-time feedback to snowboarders on the slope. In this experiment, participant received spoken instructions before a ride. During the exercise, tactile feedback was provided by the coach. The tactile feedback is presented on the body part that needs to be adjusted or is involved in the movement. The placement of the tactile feedback is seen in Figure 2.6. It was found that snowboarders perceived the tactile instructions during snowboarding. However, if participants experienced high cognitive load while learning a new exercise, they found it difficult to pay attention to the given tactile instructions. Therefore, Spelmezan et al. [15] recommend to use spoken instructions for a new exercise. After the student acquires a basic skill for the exercise, tactile instructions can be introduce to improve the skill of the athlete. Moreover, the frequency of feedback should be omitted when the performance becomes stable, so that the athlete does not become dependent on the feedback. [15]

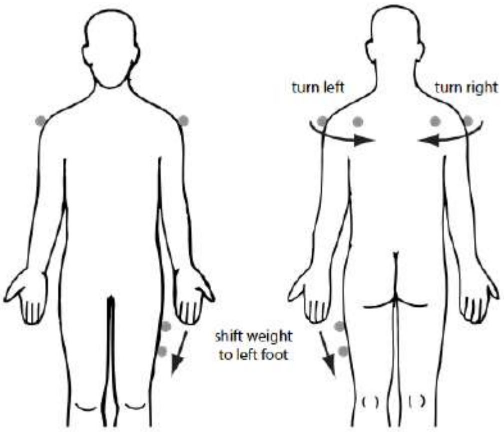

Figure 2.6: The placement of the vibration motors for real-time feedback during snowboarding. [15]

Alahakone and Senanayake [6] have made a system to provide feedback on jump landing technique. The system uses two inertial measurement sensors to measure knee abduction and knee flexion. Vibration motors are placed on the upper and lower leg (see Figure 2.7). If the target knee kinematics are reached, both actuators trigger, indicating that the landing is performed correctly. If only knee flexion or abduction is correct, the corresponding actuator vibrates. The system was evaluated with users and showed that subjects were able to responds to the vibrotactile feedback in an effective way, improving their performance. [6]

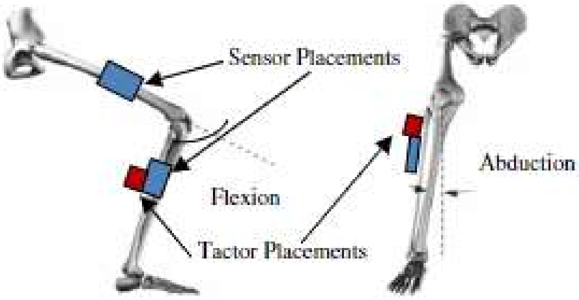

Figure 2.7: Placement of the sensors and vibration motors to monitor performance during jump landing technique. [6]

Wozniak et al. [5] have applied haptic feedback to golf. In this study, haptic, visual and auditory feedback systems were compared to provide feedback on weight imbalance and elbow bend during a golf swing. A sketch of the feedback designs is shown in Figure 2.8. For the haptic feedback design, a vibration motor was placed 5 centimetres below each knee. The participant tested all three feedback modalities. It was found that audio feedback was perceived as frustrating and resulted in more errors, compared to visual and vibrotactile feedback. Both vibrotactile and visual feedback had a positive influence on the swing quality. Moreover, the study found that both visual and vibrotactile feedback increased swing quality for golf. [5]

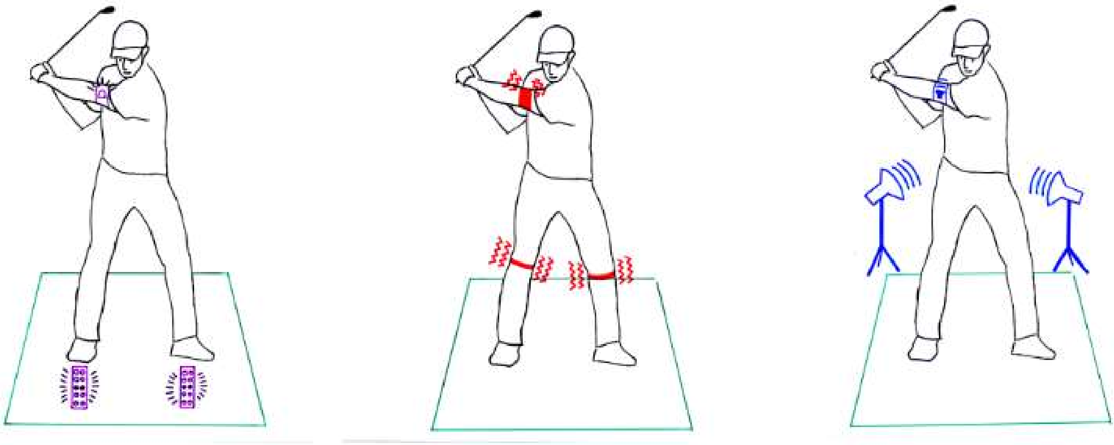

Figure 2.8: The feedback designs to provide feedback on weight imbalance and elbow bend during a golf swing. Three different modalities were used; visual (left), vibrotactile (middle) and auditory (right). [5]

Blanskma [21] has designed a haptic wearable to provide real-time posture improvements for squats. The wearable consists of two IMU's. One is placed on the front of the knee and the other of the lower back. Three vibration motors are placed on the outside of the upper leg and one on the lower back, as is shown in Figure 2.9. The system provides three types of feedback; directional feedback towards the body if the knee went over the toes; directional feedback outward if the knees should move more outward; and feedback to the lower back if the knees move before the hips move. The wearable was tested with users and the study showed that participants found the wearable comfortable to wear and that it did not hinder movement. However, not all participant found the feedback clear, which could be caused by a low intensity of the motors, incorrect timing of the motors or a lack of focus on recognition of patterns during performance of the squats. The study also found that users missed a confirmation signal when a correct squad was performed, as during a correct squat no feedback was given. [21]

Figure 2.9: The created wearable device to provide real-time feedback to the user while performing a squat. [21]

Mulder [22] has applied vibrotactile feedback to help volleyball players to shift their weight to their toes. A wearable sock was created, which would provide haptic feedback at the heel if the user should shift its weight forward. The feedback was perceived well by users and did not feel obtrusive. However, the feedback did not stimulate direct change of posture, which could be caused by the fact hat a moment of action within volleyball is short and processing the context takes a high cognitive load. More experience players were better able to process the information and improve performance compared to less experience players [22].

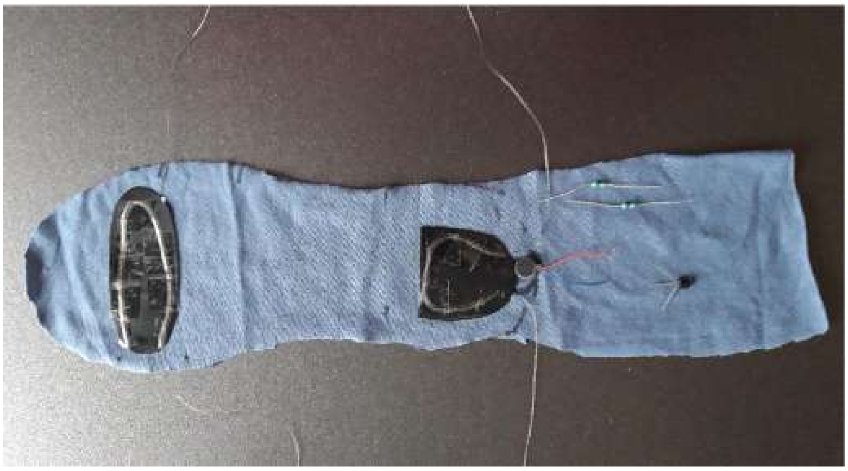

Figure 2.10: The sock used to measure and provide haptic feedback on posture during volleyball. The sock consists of sensors to measure the pressure of the foot and a vibration motor to provide haptic feedback. [22]

The Nadi X yoga pants by Wearable X[1] are a commercial product which measure posture and provide haptic feedback based on the measured posture. These yoga pants are integrated with accelerometers to measure the posture of a user, and vibration motors to provide feedback based on the measured posture. Moreover, the vibrations are used to guide the focus of the user to specific aspects of the movement. The pants can be connected to a phone using Bluetooth to monitor which exercise should be performed at what moment and how the exercise is performed. The pants of Wearable X are shown in Figure 2.11.

Figure 2.11: The yoga pants of Wearable X provide vibrotactile feedback to guide the users focus to specific aspects of the movement.

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[1] Wearable X; `https://www.wearablex.com/` *Accessed on 21-01-2022*

Systematic reviews on vibrotactile feedback in sports

The use of vibrotactile feedback in motor learning and sport has been researched in multiple systematic reviews [7, 18, 23]. The systematic reviews show that there are gaps which HCI research could fill for for wearables and tactile feedback in sports. First, Mencarina et al. [18] found that concurrent feedback is used most often while terminal feedback can also be effective. This means that the application of terminal feedback in vibrotactile wearables could be researched. Second, the systematic reviews found that most research focus on an "average" athlete, rather than specific users. This could be improved by creating solutions which can be adapted to skill level and capabilities [18, 23]. Third, one of the findings is that HCI research lacks reports on how the wearables are subjectively judged and whether athletes find them appropriate for their purpose. Contextual interviews and diaries could explore how wearables affect the athletes experience [18]. Last, wearables are often tested for a short period time, meaning that it is unclear if the wearables make their way into a sports after the novelty effect is gone [23]. Therefore, a wearable can be designed to be a temporary aid which an athlete uses while learning a new skill [23]. When creating a temporary device, retention tests should be done to see if the wearable enhances motor learning [24].

2.2.2 Vibrotactile feedback in skating

Three papers were found in which vibrotactile feedback is used during skating. A study by Jansen et al. [17] focuses on lengthening the stroke of a speed skater by providing vibrotactile feedback. Pressure sensors are placed in the skates of athletes to register their stroke and tactors were placed around the waist. The tactors started to vibrate if the skater had to push-off and stopped vibrating when the skate was placed back on the ice. The system was tested with users and the results showed that skaters were able to lengthen their skating pace to the vibrating rhythm. Moreover, the skaters got more used to the vibrations after wearing the system longer. The study does not report on how the participant felt about the system and whether they would use it more often. [17]

Figure 2.12: The final prototype for the 'Vibe of Skating' [17]

Visser and van Raamsdonk [25] created a system which can provide real time haptic feedback during speedskating. The system measures the angle of the knee using magnetic encoders. If the knee angle is too large, a vibration motor sends a signal to the user. The vibration motor was not placed at a specific location; the user would determine themselves where the haptic feedback should be provided. The system was not tested with users. [25]

Stewart et al. [26] have created a haptic device which can provide feedback based on the speed of the skaters for roller derby skating. The haptic device is attached to the wrist and the skaters tap their wrist twice to their thigh when they have done a lap. This time is used to provide a rhythm of vibrations. This way, the skaters now if they are ahead or below the recorded reference time. The device was tested with a roller derby team, which reacted positive to the device. However, there were some concerns about the safety of the device. [26]

Next to research projects, a commercial project was also involved with vibrotactile feedback in shorttrack skating; the Samsung Smart Suit[2]. This suit was created for short track athletes to measure the angles of the skaters. Based on the placement of the sensors, it is likely that inertial measurement units are used. The coach can see the data of the sensor in an app. If the coach presses the button "Go Lower" in the app, the app will sends a signal to the wristband of the skater which will start to vibrate to indicate that the skater should go lower.

Figure 2.13: Image of the Samsung SmartSuit. The suit contains of five sensors which communicate with an app. Via the app, the coach can press on the "Go Lower" button, which sends vibrotactile feedback to the wrist of the athlete.

2.3 Correct posture for inline skating

To answer the second sub question: "What defines a correct posture in inline skating?", literature research was done and two interviews were held with inline skating trainers. In this section the information from the interviews and literature research is combined to describe the correct posture in inline skating.

In inline skating, there are two techniques for a push-off. The conventional technique and the double push technique. The convectional technique is very similar to the technique used in speed skating on ice. This technique consists of three phases; a push, a glide and a recovery phase [27]. First, a skater is glides on one leg, for example the right leg, with a bend knee. The centre of mass moves to the left and the skater straightens the right leg to push off. After the push off, the left leg is set-down and becomes the new support leg, while the right leg is brought back underneath the skater (recovery phase). Next, the push off is done in the other direction. This cycle repeats during skating.
The double push technique consists of four phases; the push, set-down, pull and recovery [27]. For the double push, the second push is similar to how it is done in ice skating. After the regular push, the recovery skate is set-down on the outside edge and pulled underneath the body, creating the first push. Next, the skate is steered outwards to do the second push, which is a regular push as described above. The double push technique allows to generate more force during one stroke compared to the conventional technique. The trajectory of one skate during a conventional push-off and double push can be seen in Figure 2.14. [27]

The postures for inline skating and speed skating are similar to each other. The skating posture can be described by two angles; the knee angle and the trunk angle which are portrayed in Figure 2.15. Both angles are important to reduce air friction during speed skating. Moreover, a small knee angle allows the

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[2] Samsung Smart Suit `https://www.samsung.com/nl/samsungsmartsuit/`; *Accessed on 18-02-2022*

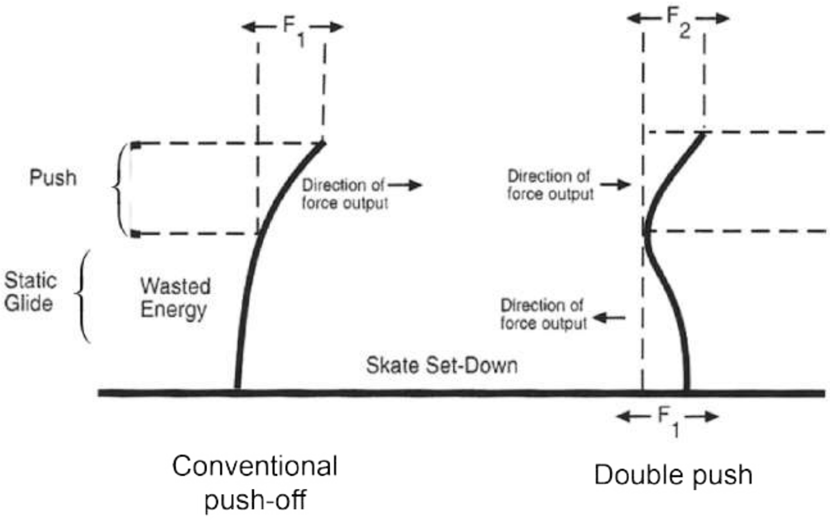

Figure 2.14: The difference in trajectory of a skate between the conventional classic and the double push technique. The double push allows a skater to apply propulsive force at two separate times. [27]

skater to generate more energy during a push off, as the push off leg can be straightened more.

De Koning et al. [28] and van Ingen Schenau [29] measured knee and trunk angles during skating. Van Ingen Schenau found that aerodynamically, the optimal trunk position is 15 degrees. Angles larger than 15 degrees result in lower speeds with equal power outputs [29]. According to De Koning et al. [28] all-round speed skaters have a the trunk angle which ranges from 10 to 30 degrees. For all round speed skaters, the measured knee angles ranging from 100 to 130 degrees [28, 30]. For elite skaters the knee angle is between 90 and 110 degrees [31].
De Boer et al. [2] compared the posture during speed skating and inline skating and found that the knee angle was larger in inline skating compared to speed skating. In speed skating, an average knee angle of 112.9 degrees was measured while in inline skating, an knee angle of 118.1 degrees was measured [2].

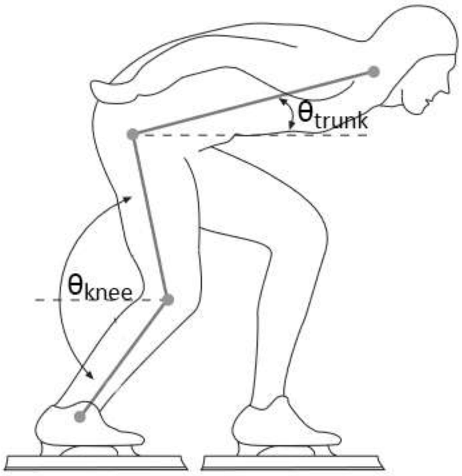

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Figure 2.15: The skating posture is defined by two angles. The trunk angle and the knee angle. The best trunk angle aerodynamically is 15 degrees. The knee angle ranges between 90 and 110 degrees for elite skaters. [28]

The values found in literature for a skating posture correspond with the mentioned angles during the interviews with the trainers (see Appendix A). The trainers mentioned that the perfect posture depends on the discipline. For short distances, the aim is to be compact as possible, thus to have a small trunk angle and a small knee angle. However, for longer distance skating, the knee angle and trunk angle should be larger to conserve energy. This means that for short distances, the knee angle could be 80 degrees, while for longer distance, a knee angle of 110 or 120 degrees is more suitable.

The trainers also mentioned other aspects of the posture to be important. For example, the knees should be pushed forward so that the knees are placed above the toes. This causes your shoulder, knees and toes to be in one straight line. If the knees are not pushed forward enough, the weight of the skater is placed to much on the back of the heels, which causes the skater to fall backwards. Another aspect of the posture is to keep a round back, by tilting the pelvis backwards. According to the trainers, if the pelvis is not titled correctly to make a round back, it is more difficult to do a proper push off during skating.

According to the trainers, there are different ways in which a posture can be done incorrectly. Figure 2.16 shows one correct posture and four incorrect postures. The first common mistake is a too large knee and hip angle (Figure 2.16b). Keeping a small knee angle is tiring, which is why skaters slowly move up after a couple of laps. However, a large knee and hip angle increase air resistance, slowing the skater down. The second common incorrect posture is to move the nose down instead of the hips. This occurs when skaters think they have a small knee angle as there head is low to the ground. This posture shifts the weight of the skater to the front, which makes it difficult to use their strength efficiently. The posture is shown in Figure 2.16c. A third common mistake happens when skaters find it difficult to keep a round back (Figure 2.16d). This happens if the pelvis is not tilted correctly, which limits the skater to do an effective push off. Furthermore, a straight or hollow back can lead to pain in the back when skating for a longer period of time. The last incorrect posture occurs when the knees are not pushed forward (Figure 2.16e). If skaters do not push their knee forward, but reduce the knee angle, their weight is placed too much backwards, which causes the skaters to fall backwards.


(a) Correct posture (b) Knee and hip angles too large (c) Knee angle too large and hip angle too small (d) Hollow back (e) Knees not pushed forward enough

Figure 2.16: Examples of the correct and incorrect postures that occur during speed skating.

In conclusion, a correct posture should aim at a trunk angle of 15 degrees and a small knee angle. The knee angle should be maintainable for the period of the skated distance. Therefore, for longer distances larger knee angles are more suitable (110 to 120 degrees) than smaller angles, which are better for short distances (90 degrees). Moreover, the knees should be pushed forward, so that the shoulder, knees and toes are in one vertical line. Lastly, the pelvis should be tilted so that a round back is formed during skating.

2.4 Posture measurements

This section focuses on wearable sensors which can measure joint angles. Methods which are not wearable such as motion capture systems and electromagnetic tracking systems are not taken into account. Furthermore, systems which are used to measure gait but are not useful for angle measurements are not taken into account, such as electromyography [32].

Magnetic Encoder Visser and van Raamdonk [25] have created a real-time haptic device which can measure knee-angles during skating and provide haptic feedback. To measure knee-angle a magnetic encoder is used. The data from this encoder is send using Bluetooth to a microcontroller, which controls the vibration motor. A magnetic encoder consists of a magnet and a magnetic sensor (a Hall sensor). The magnet is attached to a rotating body, while the Hall sensor is fixed. This is shown in Figure 2.17. The change in magnetic field can be detected and thus rotation can be measured. In this study, the magnetic encoder has not been implemented into a wearable or tested on humans. Therefore, it is unclear whether the sensor works in a wearable for skating [25]. Advantages of magnetic encoders are that they are low cost, contactless, reliable and have long lifetimes [33].

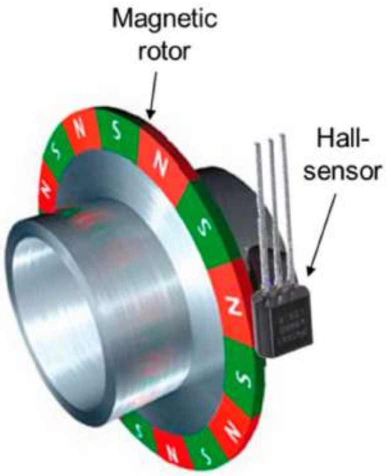

Figure 2.17: Example of how a magnetic encoder works. The encoder has interchanging north- and south poles. The hall sensor detects magnetic change, which can be used to determine the rotation angle.

Rotary potentiometer A rotary potentiometer is a passive electronic component. A potentiometer works by sliding a contact across a uniform resistance. The entire input voltage is applied across the whole length of the resistance, and the output voltage is the voltage drop between the fixed and sliding contact. Based on the difference in voltage, it is possible to determine the rotated angle of the potentiometer.
Toffola et al. [34] used a rotary potentiometer to measure knee angle. The potentiometer is attached to the side of the angle and can measure the angle. The researchers selected this potentiometer to keep the design simple, robust and cost effective. [34]

The downside of both the rotatory potentiometer and the magnetic encoder is that the sensor should be placed exactly at the joint centre [33]. If the sensor is not correctly aligned, measurement errors will occur [35]. This means that for inline skating, the sensors should be attached to a material which does not slide down during skating, such as a brace.

Inertial Measurement Units Inertial measurement units (IMUs) have been used in tennis, football, swimming, running and hockey to measure the kinematics of athletes [23]. Inertial measurement units consist of one or a combination of accelerometers, gyroscopes and magnetometers. An accelerometer measures the linear acceleration in three orthogonal direction; the X, Y and Z-axis. The accelerometer assumes that the Z-axis is aligned with gravity and gives X and Y orientations. Therefore, an accelerometer can be used to measure static orientation [36]. A gyroscope provides angular velocity around the

X, Y and Z-axis. The sensor provides an estimation of sensor orientation by assuming the known initial orientation [36]. A magnetometer provides the orientation relative to the Earths' magnetic field, which is the sensor orientation around the Z-axis. By combining the three different sensors, it is possible to get an accurate sensor orientation [36]. IMUs can be used to calculate 3D linear acceleration, angular velocity, flexion angle and orientation with respect to a reference system [37].
Poitras et al. [36] did a systematic review on the validity and reliability for IMUs for joint angle estimation. According to the systematic review IMUs are a valid method to measure joint movement for flexion or extension movements in the knee, hips and tilting of the pelvis [36]. To measure joint flexion, two calibrated IMUs are used placed above and below the joint [38]. Most commercial IMU boards come with integrated wireless module, making it easy to use in prototyping [38].
The advantage of IMUs is that they do not require tight coupling between two parts of movement. This makes the IMU easier to install compared to magnetic encoders. The disadvantages of IMUs are that they need to be properly calibrated before use, electromagnetic noise can disturb measurements and the sensors experience drift [36].

Flex sensors A flex sensor is a flexible sensor which can be used to measure joint movement [38]. The pressure generated by the joint causes resistance across the sensor. The change in resistance is directly related to the corresponding joint angle. Flex sensors can be stitched into fabric which is placed over or under the joint [39, 40]. In the study of Masdar et al. [39] two flex sensors were placed below the knee to measure the knee angle. The study used multiple sensors to measure one angle to get more accurate results [39]. The results show that flex sensors are suitable to measure joint flexion over time [39]. One downside of flex sensors is that the precision of the measurements reduces over time. [41]

Optical fiber sensors Optical fiber sensors (OFS) measure a change in light transmittance. They are composed of three parts; a light source, an optical fibre and a photo diode. Based on the light intensity attenuation, it is possible to measure the bending angle of the optical fiber. An example of how an optical fibre works is shown in Figure 2.18. Advantages of OFS are that the optical fibre is not influenced by electromagnetic noise and that the sensor is flexible, making it easy to implement in clothing [42]. However, affordable OFS-based systems have a lower sensitivity compared to IMUs [37].

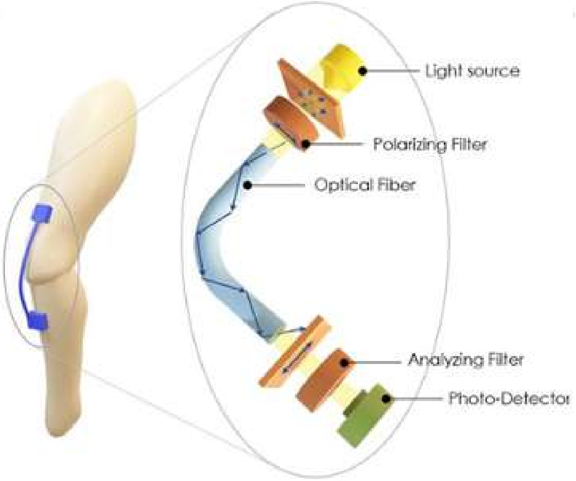

Figure 2.18: Example of an optical fiber sensor. [37]

Conclusion on sensors

The magnetic encoder and rotary potentiometer are not suitable to measure knee joint angle during skating, as the sensors need to be placed exactly at the same position each time. Moreover, if the sensor slides down, the measurements change which make the sensors unsuitable. This problem could be overcome with a brace, but a brace hinders movement during skating, which means that this is not suitable for inline skating. This leaves three suitable sensors, which each have their own disadvantages;

the inertial measurement unit, the flex sensor and the optical fiber sensor. The inertial measurement unit experiences drift, which can be a problem if the wearable is worn for a longer period of time. The flex sensor loses precision over time and the optical fiber sensor has a low sensitivity. Therefore, it is not possible to say which sensor is preferable for wearable based on this literature research. To select the best sensor, the different sensors are tested in the ideation phase to see which sensor is most accurate for inline skating posture measurement.

2.5 Vibration motors

Vibrotactile feedback can be delivered using vibration motors. In this section, the different vibration motors are explained.

2.5.1 ERM and LRA

There are two widely used vibration techniques; Eccentric Rotary Mass (ERM) and Linear Resonant Actuator (LRA). Both LRA and ERM motors are driven by a Pulse Width Modulation (PWM) signal (see Figure 2.19) [43]. A PWM signal is a signal which switches between turning on and off. This can be used to simulate lower voltages than a micro controller can output. The average supplied voltage is proportional to the duty cycle [43].

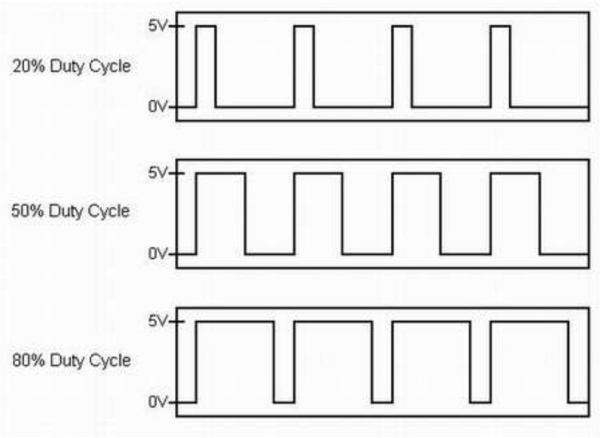

Figure 2.19: A PWM signal works with duty cycles. The duty cycle determines how long the signal is on and how long the signal is off.

The most commonly used vibration motor is the ERM. ERMs are used in alerts and haptic feedback mechanisms. The motor provides vibration feedback in two axis, due to the non-symmetric eccentric rotary mass inside the motor. ERM is a DC motor, which means that PWM is needed to get different vibration frequencies [43]. The frequency and amplitude of the ERM changes linearly to the supply voltage [44].

LRA vibrators came relatively recently on the market and were developed to have a longer lifespan and to create a more precisely targeted vibration compared to ERM motors [45]. However, LRA motors are generally more expensive compared to ERM motors and rely on AC voltage. LRAs consist of a magnet, voice coil, wavespring and moving mass. When voltage is applied to the motor, the Lorentz Force is generated due to the magnetic interaction between the coil and the magnetic field. This magnetic field applies a force to a moving mass, which is attached to a wave spring placed at the centre of the vibration module. The mass is restricted to back and forth, which means that the vibration of a LRA module is only in one direction. [43]

Multiple studies have compared LRA motors and ERM motors. The study of Huang et al. [44] found that LRAs have a lower detectable level and smaller power consumption compared to ERMs. However, ERMs have a higher detection rate. According to Huang et al. [44] LRAs are better when low power is needed and only binary information is send. ERMs are more suitable for encoding more complex signals [44]. Moreover, the study of Seim et al. [45] found that the ERM motors were easier to perceive than LRAs in general. Moreover, according to Silvia et al. [46] one ERM motor provides a good quality vibration, while two LRA motors are needed for this.

2.5.2 Form factor

Vibration motors can have different shapes. Two common types are coin motors and cylindrical motors [47]. The different motors can be seen in Figure 2.20. The main difference between the motors is their rotating axis. The coin motor rotates in a parallel to surface, while the cylindrical motor rotates orthogonal to the surface [47]. Coin motors are already in a housing, while cylindrical motors should be mounted into an tube to avoid touching the rotating mass. This creates encapsulated cylindrical motors. Schätzle et al. [47] have compared the coin motor and cylindrical motor for perception on the arm and found that the users preferred the cylindrical motor over the coin motor. Moreover, users preferred the use of two motors which rotated in opposite direction in stead of both motors rotating in the same direction. Recinos and Demircan [48] have compared a cylindrical and coin motor on perception on the foot. They found that the cylindrical motor performed slightly better for identification accuracy of a location. However, there was no statistically significant difference between the two motor types for perception accuracy [48]. When comparing the motors, it is also important to take into account the surface area of the motor. A larger surface area produces a higher sensitivity the motor. This means that larger motors are more easily perceived compared to smaller motors [49].

(a) Coin motor (b) cylindrical motor (c) Encapsulated motor

Figure 2.20: Three different types of vibration motors.

2.6 Vibrotactile feedback design

There are multiple factors to take into account when designing vibrotactile feedback. In this section different factors influencing vibrotactile feedback design are discussed. In section 2.6.1, timing, frequency and content of feedback in motor learning is discussed. Section 2.6.2 discusses the factors which influence the perception of vibrotactile signals, such as placement, pattern, frequency and intensity.

2.6.1 Feedback design in motor learning

In motor learning, augmented feedback is often used to accelerate learning. Augmented feedback is defined as ”information that cannot be elaborated without an external source” [9, p.22]. Augmented feedback can be provided by a coach, trainer or interactive system. When designing haptic feedback to accelerate motor learning, there are multiple aspects to take into account such as timing, frequency and content of the feedback [50]. In this section, these different aspects of feedback design are discussed.

Timing Feedback can be provided during a motor task (concurrent feedback) or after a motor task (terminal feedback). Concurrent feedback makes it possible to provide real-time feedback on a motor task. The feedback can be effective to boost performance, if task complexity is high and during early stages of learning. One drawback of concurrent feedback is that athletes can become dependent on the concurrent feedback during the execution of a movement. Terminal feedback is effective in tasks with both high and low task complexity. Terminal feedback can be provided with a small delay after the exercise. This allows the athlete to self-reflect on the movement which enhances learning. In general, terminal feedback is more effective for motor learning compared to concurrent feedback. [50]

Frequency The frequency at which feedback is provided has an influence on the effectiveness of the feedback. If functional task complexity is high, feedback after every trail is beneficial. If the functional task complexity lowers, the frequency at which feedback should be provided should decrease as athletes can become dependent on feedback. Therefore, there are multiple feedback schemes which can be used to provided feedback. The different schemes are discussed below [50]:

- **Fading feedback**; The frequency of feedback is high in early stages of learning and gets lower when the skill improves.
- **Bandwidth feedback**; Feedback is only provided if an athlete shows an error in a pre-defined bandwidth.
- **Average feedback**; after a number of trials, an average estimation of the performance is provided to the athlete.
- **Summary feedback**; After a training session, a summary of the performance is provided to the athlete.
- **Self-selected feedback**; Athletes get feedback when they indicate that they want feedback. Self-selection feedback is linked with a high level of motivation for athletes.

Content of the feedback Feedback can be focused on the outcome of an action (knowledge of results) or on the behaviour that led to that outcome (knowledge of performance). Knowledge of performance is useful to identify what movements lead to error in performance and is more effective compared to knowledge of results. Moreover, feedback can also be descriptive or prescriptive. Descriptive feedback describes what happened and prescriptive feedback describes what should have happened. In general, prescriptive feedback is more effective [50]. Lastly, feedback can be positive or negative. Positive feedback focuses on what is done right, while negative feedback focuses on what is went wrong. Positive feedback is useful to motivate people, while negative feedback is more effective to promote motor learning considering that error serves motor learning [50].

2.6.2 Vibrotactile signals

The design of vibrotactile signals is important, as simple and intuitive vibrotactile cues can ease workload, while cues which require more training can add to cognitive workload [51]. This section describes multiple factors which are important for the design of vibrotactile signals.

2.6.2.1 Placement of actuators

The sensitivity of the skin to vibrations varies throughout the body [52] and depends on vibration frequency, stimulus intensity, contact area, stimulus duration, skin temperature and age. The sensitivity for each part of the body can be seen in Figure 2.21. A lower threshold value indicates a higher sensitivity. For areas with a lower sensitivity, the vibration intensity could be lower to perceive the vibration comfortably compared to areas with a higher sensitivity [52]. When providing spatial cues, such as turn left, effective design of tactile feedback requires the spacing of tactors on the body to be greater than the two-point threshold for vibration. This is the minimal distance at which two points of stimulation are reported [53].

According to Bark et al. [54] the sensitivity of vibrations can be reduced when people are in rapid motion, as the background levels of acceleration can mask the vibration signal [54]. This could have implications for inline skating. Inline skating is performed on irregular surfaces which cause vibrations

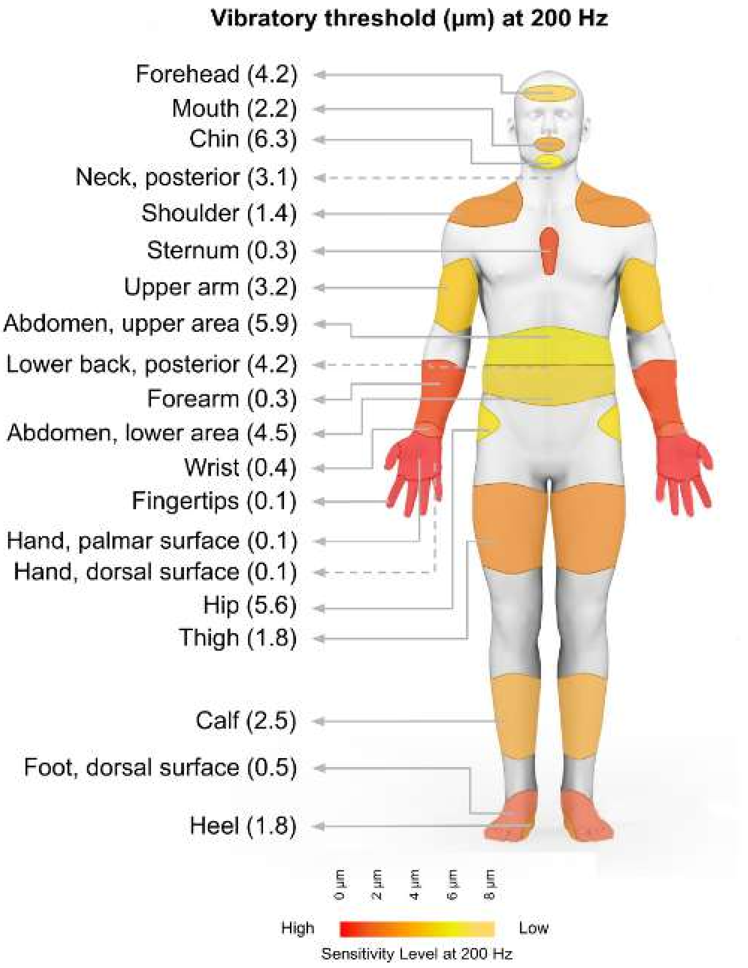

Figure 2.21: Sensitivity to vibration for different body parts. A lower value means a higher sensitivity. Adapted from [52]

transmitted to the lower limbs [55]. According to Thompson and Bélanger [55], vibrations caused by inline skating have an influence on proprioception, strength and causes numbness [55]. Therefore, a test should be held to detect whether tactile vibrations are perceived by athletes during inline skating.

The placement of the actuators on the body influence the interpretation of tactile cues [56] and is related to the intuitiveness of vibrotactile cues [51]. If the placement of the tactors correspond with the tasks, the information is easily recognisable [51]. Moreover, the response time to vibrotactile cues decreases if vibrotactile feedback is positioned at the body part which initiated the movement [52]. However, according to Islam and Lim [52], vibrotactile feedback located at a moving body part can be perceived as confusing, which is why Islam and Lim recommend an investigation to determine what placement of tactors is effective [52].

Another factor to take into account is the type of tissue on which a vibration motor is placed. Spelmezan et al. [57] investigated perception to vibrotactile motors and found that vibration on bones feels stronger compared to vibration on softer or muscular areas. Vibrations which are perceived stronger could represent more powerful movements compared to softer vibrations [56].

If multiple vibration motors placed on different locations are used simultaneously, the perception accuracy lowers [51, 58] and it can confuse the users [59, 60]. Moreover, if multiple vibration motors are activated during a motion, it is more difficult to process feedback compared to one activated motor [51]. Therefore, McDaniel et al. [61] recommend that vibration patterns which target different movements should not share motors to improve distinctness between actions. Moreover, if feedback should be provided to multiple parameters of a movement, it is recommended by Lurie et al. [60] to provide feedback to one parameter for some time before moving to another, so that the user has time to adapt to the feedback [60].

Placement at the knees To provide feedback on knee kinematics, vibration motors can be placed on different locations. For example on the inside or outside of the knee [58, 59], on the calf [6], on the wrist[3] or on the outside of the thighs [21, 62]. For knee flexion, the study of Alahokone and Senanayake provided tactile feedback to the calf. If the required knee angle was reached, the vibration motor would be triggered [6]. Blanksma used three motors on the upper leg to indicate to move knees more inwards or outwards during a squat [21]. Moreover, Spelmezan et al. [57] found that directional feedback delivered at the back of both thighs resulted in a slight preference to ”bend the legs” compared to directional feedback delivered to the front of the thighs [57]. However, it is also possible to provide feedback on another position of the body, which is what Wheeler et al. [63] and the Samsung SmartSuit[3] did. In these studies, feedback was provided to the lower arm [63].

Based on the different researches which provided feedback to the knee, there is no clear consensus were the haptic feedback should be placed. As mentioned before, information is most intuitive if the placement of the motors corresponds with the task [51]. However, this could be placed on the knee, calf or thigh. Therefore, a study could be done to see where actuators should be placed to provide intuitive and easily recognisable feedback.

Placement on the back Peeters et al. [4] investigated tactile feedback for posture correction in cycling. For this, the vibrotactile motor was placed on the C7 vertebrae, which is on the back of the neck. The vibration reminded the person to keep the aerodynamic position [4].
For correct seating posture, vibrotactile feedback is provided to the torso. This can be done at the upper back[4], at the collar bone[5] or at the lower back [64]. Spelmezan et al. [57] investigated how users interpret tactile sensations all over the body. It was found that vibrotactile signals at the upper back were interpreted as ”straighten up” or ”lean backwards”. Feedback provided to both shoulders were interpret as ”pull shoulders back” [57].

Again, there is no clear consensus on where vibration motors should be placed to provide intuitive feedback for the user. Therefore, research could be done to find out what placement is most intuitive to stimulate a round back during inline skating.

2.6.2.2 Patterns

With the use of vibration motors, vibrating patterns can be created. This section describes different patterns that can be created with multiple vibration motors.

One type of pattern which can be created with multiple vibration motors are vibrotactile illusions. There are two types of vibrotactile illusions; sensory saltation and funneling (see Figure 2.22). Sensory saltation creates the feeling that a signal travels between 2 or more actuators which are activated with different time intervals [65]. Typically the interstimulus intervals should be between 20 and 300 ms, where 50 ms is the optimal time interval [53]. Saltation requires more information processing compared to cues given by stationary vibrations [66]. This results in a high reaction time, which makes saltation less suitable to be used for real-time motion correction compared to stationary vibrations [51]. With funneling, a user perceives a signal which is perceived in the middle of 2 simultaneously activated actuators [65]. Funneling only occurs if the two stimuli are close enough, which depends on the sensitivity of the body part [67].

Spelmezan et al. [56] has investigated the best pattern to indicate rotation around the torso. The study found that patterns which included vibrations around both shoulders were preferred over vibrations around one shoulder and that patterns with a single motor pulse were preferred over patterns with triple pulses. To some participants, the patterns with multiple pulses per motor felt slower and seemed to

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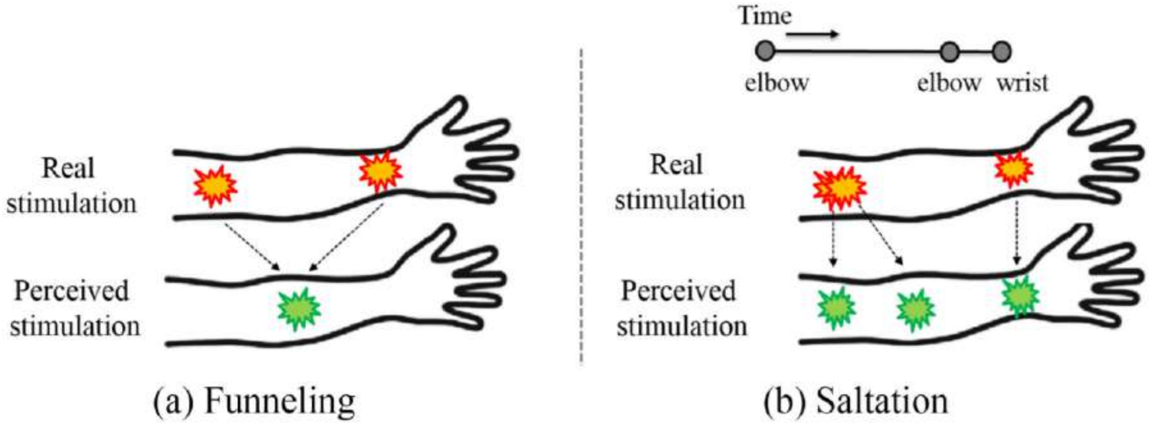
[3] Samsung SmartSuit `https://www.samsung.com/nl/samsungsmartsuit/`; *Accessed on 03-03-2022*
[4] URIGHT POSE `https://www.uprightpose.com/`; *Accessed on 03-03-2022*
[5] Lumo Lift `https://feelpeak.com/lumo-lift/`; *Accessed on 03-03-2022*



(a) Funneling (b) Saltation

Figure 2.22: Funneling elicits a sensory sensation between two simulated locations. Saltation gives the illusion that a signal travels between 2 or more actuators. Figure from [68].

request slower turns compared to single pulses. Another finding was that directional patterns take up a higher cognitive load compared to non-directional patterns and are therefore more likely to get mixed up during exercise, compared to non-directional patterns [56].

When creating a vibrotactile pattern, the pulse duration, pulse repetition and number of pulses can be changed. Usually, a pulse ranges between 80 to 500 ms [53]. The pulses are often repeated in a sequence of on and off pulses. If a pulse length increases, the pulse is better perceived. If the signal is used as an alert, a pulse between 50 and 200 ms is beneficial, as longer pulses are perceived as annoying [53]. According to McDaniel et al. [69] gentle pulses of 120 ms on and 120 ms off mimic a gentle ”tapping” signal which feels natural for guiding a limb [69].

A vibrotactile signal can be interpreted in different ways. According to Spelmezan et al. [57] a vibrotactile signal can ”push” or ”pull” towards a movement. Spelmezan et al. [57] studied whether the ”push” or ”pull” mapping of vibrotactile feedback influences identification accuracy. Two groups were made. For one group (intuitive group) the instructions were encoded according to the participants preferred method and for the other half, the instructions were encoded to be counter-intuitive. The study found that there was no significant difference between the accuracy of interpretation of cues while stationary [56]. Lurie et al. [60] and Luces et al. [70] compared the ”push” and ”pull” mapping to see which mapping is preferred. Lurie et al. [60] performed a study on 9 subjects and found that the 7 out of 9 preferred the ”pull” mapping [60]. Lucas et al. [70] also found that the ”pull” mapping resulted in the best result to let a user guide its wrist to a desired position.

McDaniel et al. [61] compared a push/pull metaphor and a ”follow me” concept. The idea behind the ”follow me” mapping is to follow the direction of the vibration pulses as they move along the skin. The push/pull concept used multiple vibration motors, in which the direction of the vibration motor pushed or pulled towards flexion or extension. The study found that push/pull patterns were most natural for flexion and extension, but that the ”follow me” principle is better for abduction/adduction and rotations. However, in a later study [69], it was found that switching between conceptual mappings was confusing for participants. Therefore, it is recommended to use one consistent conceptual mapping for different movements [69].

2.6.2.3 Frequency and intensity

This section describes how intensity and frequency influence the perception of vibrotactile feedback [9].

The optimal sensitivity of the skin to vibrations is between 150 and 300 Hz [53]. According Jones and Sarter [53] a sense of urgency can be conveyed by increasing the frequency of the signal, whereas caution can be represented by decreasing the frequency. However, the sensitivity to vibration changes per body part and not all frequencies can be distinguished. Therefore, Jones and Sarter [53] state that

it is unclear whether frequency is a useful parameter to use to vary.
Next to frequency, the intensity of the vibration can be altered. According to Spelmezan et al. [56] intense perceived vibrations can be used to represent intensive and powerful movements, such as jumping [57]. Changes in intensity at a constant frequency influence the perceived amplitude and frequency of the signal. Therefore, it is recommended to adapt only frequency or intensity and not both.

2.6.3 Conclusion

The design of vibrotactile feedback can be divided into two parts; the design of the feedback itself and the design of the vibrotactile signal. For feedback design, timing of the feedback, frequency feedback schemes and the content of feedback are important.
When designing vibrotactile feedback cues, it is important to keep the cues simple and intuitive, so that the cues do not cause a high cognitive load. Therefore, the the placement of actuators and vibrotactile patterns should be taken into account. To ensure good perception, the frequency, intensity and duration of signals are important. For the placement of actuators, some body locations are more sensitive than others. Moreover, vibration motors on different locations should not be used simultaneously as this lowers perception accuracy and is confusing for users. The literature research showed that there are no guidelines on where to put tactors for a certain motion or cue, such as "make a round back" or "bend your knees". Therefore, research could be done to where vibration motors should be positioned to provide intuitive feedback for those movements.

When multiple actuators are used, it is possible to create saltation patterns and directional patterns. However, saltation and directional patterns require more information processing compared to stationary vibrations which causes a higher reaction time. This makes saltation and directional patterns less suitable for real-time feedback compared to stationary vibrations. Vibration motors can "push" or "pull" towards a motion. The studies investigating the "push" and "pull" mappings found a slight preference for the "pull" mapping. However, when designing feedback, the designer should stick with one mapping for all different movements to avoid confusion.

Next, frequency, intensity and duration all influence the perception of signals. If the intensity changes while the frequency is similar, the perceived frequency changes. Therefore, only one of the two parameters should be altered if it is used to convey information. However, placement and duration are the most promising methods to encode information, considering that frequency and intensity modulations are not well perceived by the body.

2.7 Conclusion

The aim of the context analysis is to get insight on the design of haptic feedback for posture correction in inline skating. With the gained knowledge from the context analysis, it is possible to answer sub question 1 and 2. However, the context analysis did not provide enough information to answer sub question 3 and 4. For these sub questions, new questions arose which are answered in the remaining chapters of the thesis. This section goes over each sub question and answers the question or describes which questions should be answered during the thesis. The conclusion ends with the refined research questions.

SQ1: What is the state-of-the-art of vibrotactile feedback in sports?

The state-of-the-art overview of vibrotactile feedback in sports shows that vibrotactile feedback has been applied to many different sports (e.g. cycling, mountain biking, golf, snowboarding, volleyball, squats) to enhance posture correction. The studies show that vibrotactile feedback is well perceived during exercising and can be used to improve performance. The systematic reviews on vibrotactile feedback in sports indicate gaps which research can fill. For example, vibrotactile feedback in sports uses mostly concurrent feedback, while terminal feedback could also be effective. Next, wearables are created for an "average" athlete, rather than for specific athletes. To improve this, wearables can be created which can be adapted to the skill level and capabilities of users. Another solution would be to create temporary aids which the athlete uses during a certain stage of learning a new skill.

The state-of-the-art overview in skating shows that there are projects which focus on posture during ice skating, such as the project of Visser and van Raamsdonk [25] and the Samsung Smart Suit. These projects measure posture during speed skating and provide feedback to the user. Unfortunately, these projects only provide feedback on one part of the skating posture and did not research the best method to provide feedback during skating.

SQ2: What defines a correct posture in inline skating?

Based on the literature research and interviews with trainers of inline skating, a description of the correct inline skating posture is made. A correct inline skating posture consists of a small knee angle (90-120 degrees) and a trunk angle of 15 degrees to keep an aerodynamic position. The knee angle depends on the time a knee angle should be maintained, considering that keeping a low knee angle is tiring. Therefore, for short distances a knee angle of 90 degrees is optimum, but for longer distances a larger knee (110-120 degrees) angle is more suitable. Moreover, for a correct posture, the knees should be pushed forward so that the shoulder, knees and toes are in one straight line. This causes the user not to fall backwards. Lastly, the pelvis should be tilted backwards so that a round back is formed during skating. This helps to reduce air resistance and to do an effective push off.

SQ3: How to measure a correct posture in inline skating?

In the context analysis, five types of sensors were compared to determine which sensors could be used to measure the posture during inline skating. These sensors are magnetic encoders, rotatory potentiometers, inertial measurement units, flex sensors and optical fiber sensors.
Magnetic encoders and rotary potentiometers should be placed exactly at the knee joint. This means that a brace should be used to ensure that the sensors are in the correct position. Since this hinders movement during inline skating, this is not a suitable option. This leaves three suitable sensors; the inertial measurement units, the flex sensor and the optical fiber sensors.
Optical fiber and flex sensors are flexible sensors which makes them easy to implement in clothing. However, the precision of flex sensors reduce over time and optical fiber systems have a lower sensitivity compared to inertial measurement units, but inertial measurement units experience drift which can influence the measurements.
Therefore, it is unclear which sensor is most suitable to measure a correct posture in inline skating, hence the three sensors should be compared to determine which sensors best. Moreover, the location of the sensors to accurately measure posture should be determined. This results in two questions which should be answered during the thesis;

SQ3.1: What sensor works best to measure inline skating posture accurately; flex sensors, inertial measurement units or optical fiber sensors?

SQ3.2: Where should the sensors be placed to accurately measure knee angle and the curvature of the back?

SQ4: What parameters influence the design of effective haptic feedback?

The design of haptic feedback is influenced by the design of the feedback itself and the design of the vibrotactile signals. Feedback in motor learning is influenced by the timing of feedback, the frequency of the provided feedback and the content of the feedback. For timing, concurrent feedback can be used to boost performance. However, terminal feedback is generally more effective compared to concurrent feedback. If task complexity lowers, the frequency of feedback should decrease. For this, different feedback schemes can be used; fading feedback, bandwidth feedback, average feedback, summary feedback and self-selected feedback. Lastly, for the content of feedback, prescriptive feedback and feedback on the knowledge of performance is most effective. For motor learning, negative feedback is most efficient, but positive feedback is important to motivate people.

The design of vibrotactile signals is influenced by the used vibration motors, the placement of actuators, patterns, intensity, frequency and duration of pulses.

There are different types and form factors of vibration motors. This research discussed two types of motors (LRA and ERM) and two form factors (coin motors, cylindrical motors). In general, LRA motors are better when low power consumption is important, but ERM motors are easier to perceive. With regards to form factors, two studies mentioned that cylindrical motors were better perceived compared to coin motor, although one of the studies did not find a significant result. Moreover, sensitivity of vibrations can be reduced when people are in rapid motion and due to background levels of vibration. Therefore, experiment should be performed to answer the following question:

SQ4.1: What type of vibration motor provides vibrations which are pleasantly perceived during inline skating?

Next, the placement of the actuators influence the effectiveness of feedback. To ensure intuitive feedback cues, it is best to place actuators on body parts which are involved in the movement. Moreover, vibration motors on different locations should not be used simultaneously to avoid confusion for users. The context analysis did not find clear guidelines on the positioning of actuators for certain movements. Therefore, during the research project, the following question should be answered:

SQ4.2: What is the best placement of actuators to provide intuitive and pleasant perceived haptic feedback?

Moreover, vibrotactile feedback cues can be mapped to "push", "pull" or to make a "follow me" motion. The "push" and "pull" mappings have been compared in different study and there seems to be a light preference for "pull". However, considering there was no clear consensus on the best mapping, this should be tested during the research project. This results in the third question:

SQ4.3: What conceptual mapping is most intuitive during inline skating; "push", "pull" or "follow me"?

The perception of vibrotactile cues is influenced by frequency and intensity and duration. However, considering that a change in frequency and intensity is not perceived well by the body, pattern and placement are more promising to encode information. It is unclear what patterns are effective and intuitive to provide feedback during inline skating. This results in the following question;

SQ4.4: What vibration patterns are effective to coach posture in inline skating?

Refined research questions

While answering the sub questions, new questions arose. These questions are used to refine the research question and sub question. This results in the following research questions:

RQ: How to design effective haptic feedback for coaching posture in inline skating?

SQ1: What is the state-of-the-art of vibrotactile feedback for posture correction in sports?

SQ2: What defines a correct posture in inline skating?

SQ3: How can the correct posture in inline skating be measured?

- **SQ3.1:** What sensor works best to measure inline skating posture accurately; flex sensors, inertial measurement units or optical fiber sensors?
- **SQ3.2:** Where should the sensors be placed to accurately measure the knee angle and the curvature of the back?

SQ4: What parameters influence the design of effective haptic feedback?

- **SQ4.1:** What type of vibration motor provides vibrations which are pleasantly perceived during inline skating?
- **SQ4.2:** What is the best placement for vibration motors to provide intuitive and comfortable haptic feedback?
- **SQ4.3:** What conceptual mapping is most intuitive during inline skating; "push", "pull" or "follow me"?
- **SQ4.4:** What vibration patterns are effective to coach posture in inline skating?

Sub question 1 and 2 were answered in the context analysis. The other sub questions are answered in the next chapters of the research.

Chapter 3

Methods and Techniques

This chapter discusses the methods and techniques used throughout the project. The project made use of interviews, the creative technology design method and statistical tests.

3.1 Context analysis: Interviews

During the context analysis (Section 2.3), two semi-structured interviews with inline skating trainers were held to get more information on the correct inline skating posture. Both of the interviewees are trainers at a student ice skating association.
Trainer 1 gives training to a recreational group of skaters. This trainer has competed in inline skating competitions and his background is in inline speed skating. The trainer has given training session for three years now on recreational level. Trainer 2 gives training to the competition group of the association. His background is in ice-skating. The trainer himself has ice skated at the (sub)top of the Netherlands. The trainer has a lot of insights in the correct skating technique and posture.

One interview was held face-to-face and one online. The interview was a semi-structured interview. The guiding questions used for the interviews are written down below.

1. When did you start with inline skating?
2. Since when do you provide training sessions?
3. What is the ideal inline skating posture according to you?
4. What are aspects which can go wrong in the inline skating posture?
5. What do you think most skaters do incorrectly when inline skating?
6. How do you currently provide feedback to improve the inline skating posture?
7. Do you think haptic feedback can help to improve the inline skating posture?

3.2 Development of the wearable

To develop the wearable, the Creative Technology Design Method is used. The Creative Technology Design Method consists of four phases; ideation, specification, realisation and evaluation. During this research, the ideation and specification phase are combined and focus on small experiments to investigate different aspects of wearable design. In the realisation phase, the wearable is built and in the evaluation phase, the created wearable is tested in an evaluation test.
This section describes the methods used for the experiments and evaluation test.

3.2.1 Experiments

To gain insights on the design of different aspects of the wearable, small experiments were done. The experiments are done to try to answer sub question 3 and 4. Chapter 4 tries to answer SQ3, focusing on how to measure the inline skating posture. Chapter 5 and Chapter 6 contain experiments to answer SQ4. In Chapter 5 different actuator placements are investigated and in Chapter 6 different vibration patterns are tested.

The experiments in the three chapters all follow the same format. First, the research question is formulated. Next, the method which is used for the experiment is written down. Afterwards, the results are analysed. Based on these results, a conclusion is drawn. This conclusion is used to improve the design of the wearable.

All of the experiments are performed with a small number of users (4 to 5 participants). The experiments and evaluation test have been approved by the Ethics Committee of Computer and Information Science of the University of Twente, with reference number RP 2022-58. All participants were informed using an information brochure and asked to sign a consent form. The information brochure and consent form can be found in Appendix B.

Based on the results of the context analysis and the experiments a wearable is developed. This wearable is evaluated in an evaluating test in Chapter 8.

3.2.2 Evaluation test

During the evaluation phase, the created prototype to provide haptic feedback on posture during inline skating is tested with a user test. Chapter 8 describes in detail how the evaluation test was performed.

The evaluation phases uses two different statistical tests to evaluate whether the designed wearable has a significant effect on the posture of the participants. The used statistical tests are the repeated measures ANOVA and the Paired Sign Test.

Repeated measures ANOVA

The repeated measures ANOVA is a statistical method which compares group means for repeated measures [71]. The repeated measures ANOVA is used to compare the knee angle during the different trials with each other. The repeated measures ANOVA tests whether the means of the different trials are equal to each other or not.

The repeated measures ANOVA has four assumptions.

1. The observations are sampled independently.
2. The distribution of the dependent variable in the groups is approximately normally distributed.
3. The independent variable consists of at least two related groups or matched pairs.
4. Sphericity: the variances of the difference between all combinations of related groups must be equal.

The null hypothesis of a repeated measures ANOVA is that all means are equal, while the the alternative hypothesis states that not all means are equal.

H_0: The population mean of all trials are equal.

H_a: The population mean of all trials are not equal.

The repeated measures ANOVA is done in SPSS. The trials are set as repeated measures. Gender, experience and location are set as between-subject factors to investigate whether these factors have an influence on the measured knee angle. Based on the results of the repeated measures ANOVA, post-hoc tests are performed which compare the different groups in more detail. This is done with a pair-wise comparison.
The pair-wise comparison performs t-tests between the different pairs. A t-test is test which can compare the means of two different groups. However, the pair-wise comparison performs many t-tests which can result in false positive, which is why multiple testing correction should be applied [72].

For the pairwise comparison, the false discovery rate (FDR) estimation is used. The FDR is calculated using the Benjamini-Hochberg procedure. Using the Benjamini-Hochberg procedure, the adjusted p-value is calculated. During the ANOVA tests, the adjusted p-values are shown in the 'adjusted p-value' columns.

The adjusted p-value is calculated using the following steps:

1. Calculate the p-values for the different tests.
2. Rank the p-values from low to high.
3. Calculate the Benjamini-Hochberg p-values:

$$\text{Benjamini-Hochberg p-value} = \frac{\text{p-value} * \text{number of tests}}{\text{number of tests}} \tag{3.1}$$

4. Change the p-values to the adjusted Benjamin-Hochberg p-values. The resulting sequence should have an increasing p-value. If a p-value of a later rank is lower, all higher p-values of the ranks above get this lower p-value.

Paired sign test

To test whether the feedback on the back resulted in an improvement in inline skating posture, the Paired Sign Test is used. It was chosen to do a paired sign test instead of the repeated measures ANOVA as the data on the posture of back contains outliers. The paired sign test is a nonparametric test, which is not influenced by outliers. Moreover, contrary of the Wilcoxon Signed Rank Test, the paired sign test can be used for data which is not symmetric.

To do the paired sign test, the following assumptions should hold:

1. The dependent variable should be measured at the ordinal or continuous level.
2. The independent variable should consist of two categorical ”related groups” or ”matched pairs”.
3. The paired observations should be independent.

The paired sign test tests whether the medians of two samples are equal or not. This results in the following hypothesis:

H_0: The median of the difference between sample 1 and 2 is equal to zero.

H_a: The median of the difference between sample 1 and 2 is not equal to zero.

Sample 1 and sample 2 are dependent on the parameters of interest. In Chapter 8, the hypothesis are described in more detail.

Chapter 4

Posture measurements for inline skating

The aim of this chapter is do investigate how the skating posture can be measured. This is divided into two sections; (1) measuring the knee angle and (2) classifying whether a participant has a round, straight or hollow back. The aim of this section is to answer SQ3: ”How can the correct posture in inline skating be measured?”.

The system which measures the correct posture during inline skating should adhere to the following requirements:

- **The system should be able to determine whether the back of a participant is round or not.**
  To detect whether the posture of the inline skater is correct, the device should be able to detect whether a participant's back is round or not.
- **The system should be able to measure the knee angle during inline skating.**
  To measure the average knee angle and to provide feedback on the knee angle, the device should be able to measure the knee angle during inline skating.
- **The system work continuously for at least for 1.5 hours**
  A typical inline skating training is approximately 1.5 hours. The system should be able to work continuously for this period of time.

Based on the context analysis (Section 2.4), there are three suitable sensors which can be used to measure the posture during inline skating. These are flex sensors, inertial measurement units and optical fiber sensors. However, optical fiber sensors are not commercial available, which means that they are not suitable for the project. Therefore, this section compares the inertial measurement units and flex sensors to determine which sensor measures the inline skating posture most accurate. Two types of flex sensors were used. The length of the flex sensor is different. Flex sensor 1 is 7 centimeter and flex sensor 2 is 10 centimeter. The three different sensors are shown in Figure 4.1. The sensors were compared in three experiments. The first experiment focuses on classification of a round back, the second experiment on the knee angle and the third experiment focuses on the behaviour of the sensors over a longer period of time.

4.1 Experiment 1: Classification of a round back

In Experiment 1, the two flex sensors and inertial measurement unit are compared to determine which of the sensors measures the curvature of the back most accurately. This experiment has two research questions:

Exp-1.1: ”Where should sensors be placed to accurately measure the curvature of the back?”

Exp-1.2: ”Which sensor works best to measure the curvature of the back accurately; inertial measurement units or flex sensors?”

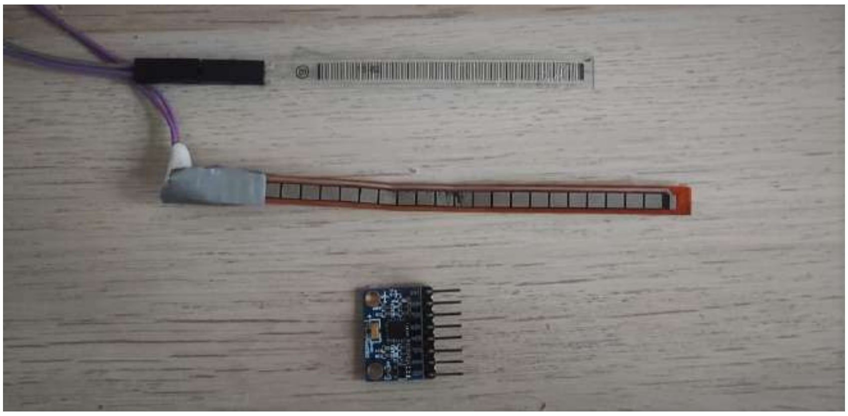
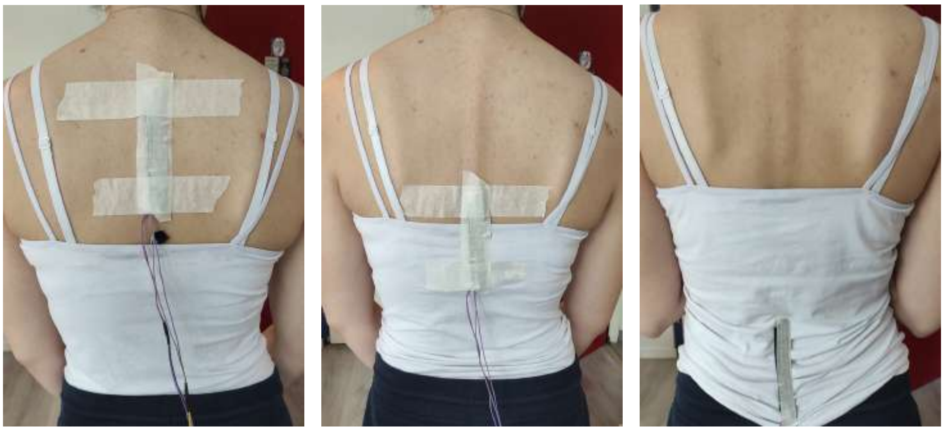


Figure 4.1: The three different sensors which are compared to detect which performs best to measure posture. From top to bottom: long flex sensor, short flex sensor and an inertial measurement unit.

4.1.1 Method

The experiment consists out of a pilot test and the experiment. The pilot test was performed to test many different sensor locations on one participant. For the flex sensors, three placements were compared; the upper back, middle back and lower back. The placement of the sensors is shown in Figure 4.2. For the inertial measurement sensors, four different sensor placement were compared; upper back, middle back, lower back and the complete back. These placement are shown in Figure 4.3. Based on the results of the pilot experiment, the three best sensor locations for each sensor were selected. These locations were tested with four participants to determine which of the sensors is most accurate measure the curvature of the back.

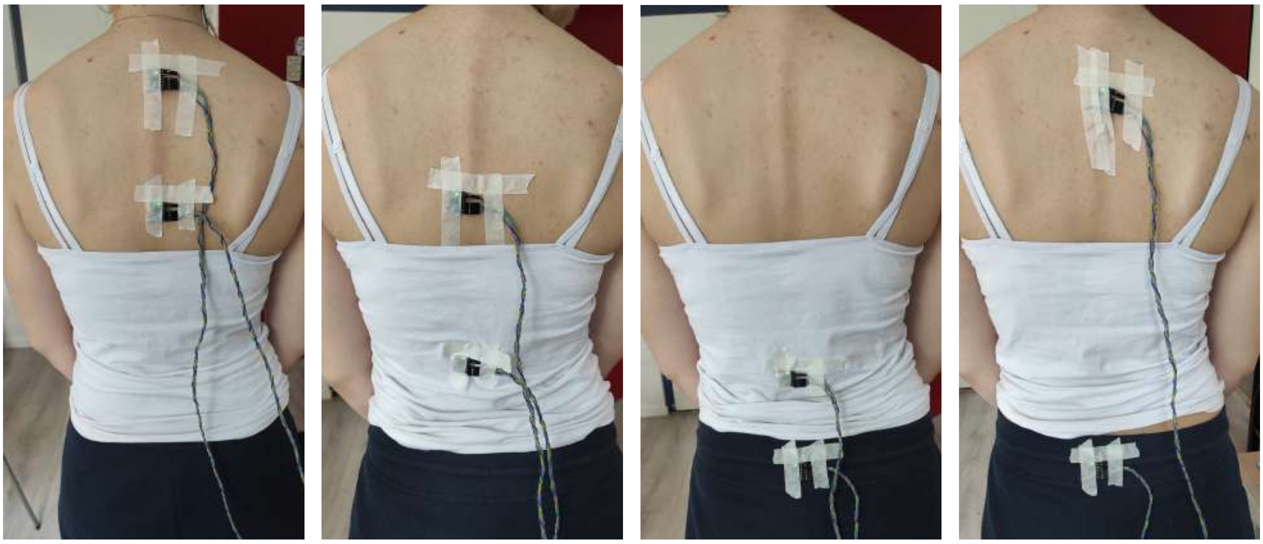


(a) Upper back (b) Middle back (c) Lower back

Figure 4.2: The placement of the flex sensors in the experiment.

During the experiments, the sensors were taped to the user's back. For the pilot experiment, this was done directly to the skin but for the other experiment the sensors were placed on top of the clothing, while participants wore tight clothing. This was done since in the wearable, the participants are likely to wear the sensors on top of their clothing. For each placement, the participants were asked to make a round, straight and hollow back while standing in the skating position. The participants were asked to hold the round, straight or hollow back for 5 seconds before moving on to the next. This was performed twice and in between the sessions the sensors were reset. The output values of the sensors are compared to see whether it is possible to classify different postures based on the sensor readings.

The flex sensor outputs an analogue value between 0 and 4095. When the flex sensor is bend, the resistance of the flex sensor goes up which reduces the voltage over the flex sensor. The ESP32 used



(a) Upper back (b) Middle back (c) Lower back (d) Full Back

Figure 4.3: The different placement of the inertial measurement units to measure the curvature of the back.

during the experiment converts the output voltage of the flex sensor from a value from 0 to 4095, where 0 corresponds to 0V and 4095 to 3.3V. This means that the flex sensor outputs a value of 4095 if the sensor is straight and a value of 0 when completely bend.

For the inertial measurement units, two inertial measurements are used to measure the different postures. The difference between the value of the accelerometer for the x-axis for both IMUs is calculated. This value is the delta. The delta is computed with the formula shown in Equation 4.1.

$$\text{delta} = \text{accelerometer}_1.x - \text{accelerometer}_2.x \tag{4.1}$$

The delta range for each of the different postures is compared to see whether the IMUs can distinguish between different postures.

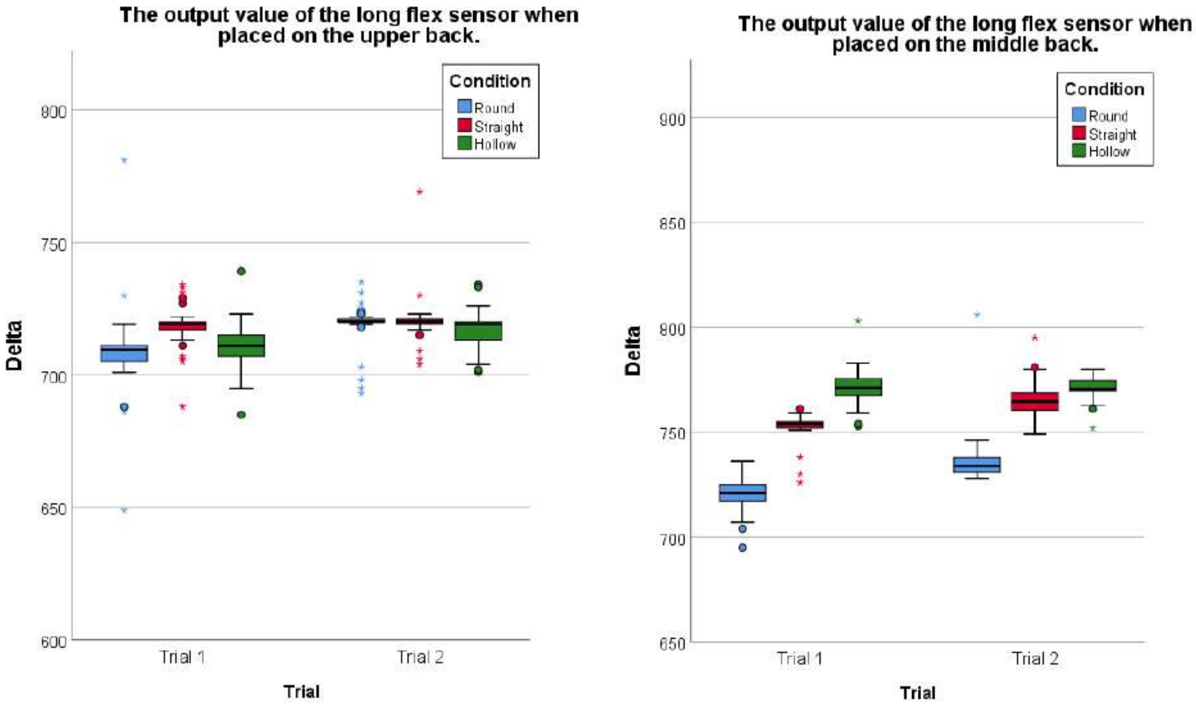
4.1.2 Results

In the first section, the results of the pilot are described. In the second section, the results of the experiment are shown.

4.1.2.1 Results of Pilot

The pilot was performed with one participant (female, age: 22). To analyse the output range of the data in different postures (straight, round and hollow), box plots for the different sensors were made (see Figure 4.4 and Figure 4.5). The box plots show the distribution of the data for each posture (round, straight or hollow back). The plots show which values and conditions overlap, indicating which sensors and sensor placement are useful to classify the curvature of the back.

Flex sensors The lower back is not a good position for a flex sensor. If a flex sensor is secured to a t-shirt, the t-shirt stretches with the back which moves the flex sensor up. However, if the sensor is attached directly to the skin, the sensor does not stay on the skin since the skin stretches but the sensor does not. Therefore, the flex sensor was not tested on the lower back. Moreover, the short flex sensor was not sensitive enough to sense changes in curvature of the back. The sensor reports a value of 4095 for each posture, which is the value that the flex sensor reports when the sensor does not detect bending. Therefore, the short flex sensor is not suitable to measure the curvature of the back.
This means that the only two suitable options are (1) the long flex sensor placed on the upper back and (2) the long flex sensor placed on the middle back. The box plots for these conditions are shown in Figure 4.4.



(a) Upper back (b) Middle back

Figure 4.4: Box plots of the output value of the flex sensor in different conditions when the sensors are placed at different locations.

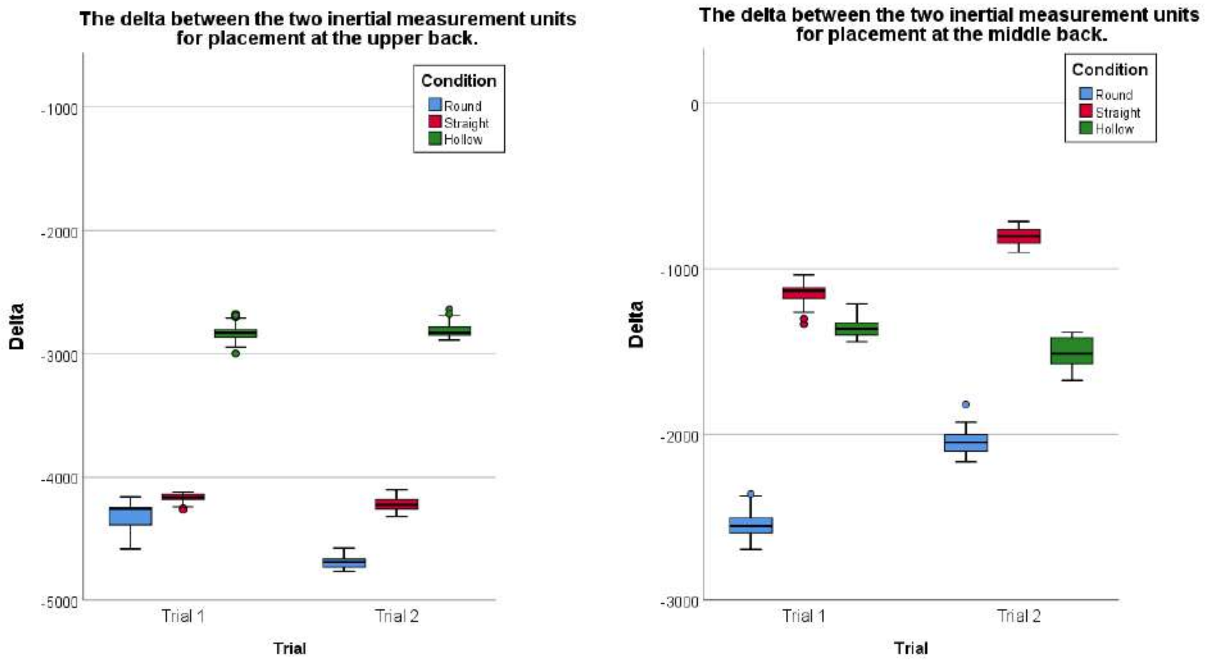
The box plot show that the distribution between the values for the different conditions is larger for the middle back (Figure 4.4b) compared to the upper back (Figure 4.4a). The values of the flex sensor placed on the upper back between a round, straight and hollow back. This means that the sensor cannot distinguish between the different conditions. Therefore, it can be concluded that when using a flex sensor, a long flex sensor placed on the middle of the back performs best to measure the curvature of the back during inline skating.

Inertial Measurement Units Figure 4.5 show the box plots for the four different placements tested with the inertial measurement units. First of all, Figure 4.5c shows overlap between the values of a straight back and values for other conditions. In trial 1, the values of the straight back overlap with values of a round back, while in trial 2 the values of the straight back overlap with a hollow back. Considering that the values overlap, it means that the sensor is not able to accurately classify the posture based on the sensor readings.
The sensor placed at the upper back (Figure 4.5a), middle back (Figure 4.5b) and full back (Figure 4.5d) do not show overlap between the values of a round, straight and hollow back. This means that these sensors could classify the different postures. When comparing the three graphs, it can be seen that the gap between the values of a round and straight back is smaller for placement at the upper back compared to the other conditions. This means that if a sensor might change slightly, it could classify a round back for a straight back and vice versa. Therefore, the placement on the middle and full back are more suitable, considering that the gap between the round back and other conditions is larger.

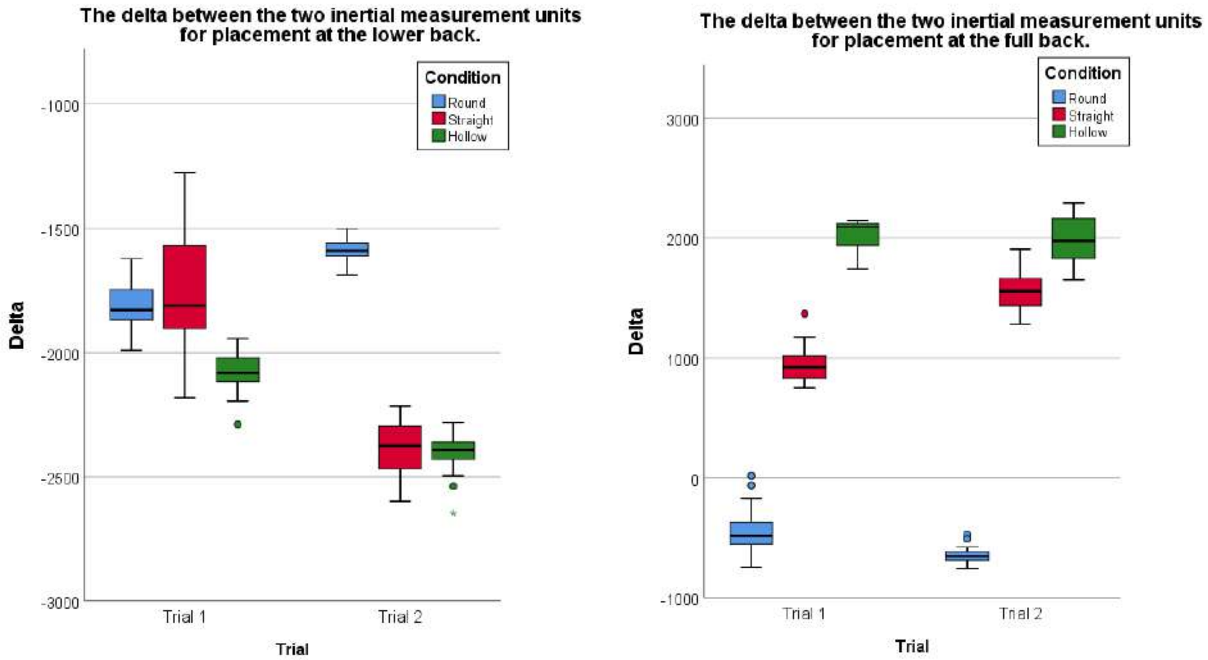
Based on these findings, there are three possible methods to classify whether a participant has a round back or not. These are: (1) the long flex sensor placed on the middle of the back, (2) two inertial measurement units measuring the middle back, and (3) two inertial measurement units measuring the full back. These placements were tested in the next experiment.

4.1.2.2 Results of Experiment

The three best sensor placements were tested with four participants. Three of the participants were male and one female. The participants were between 20 and 26 year old (mean: 22, median: 21). The results



(a) Upper back (b) Middle back

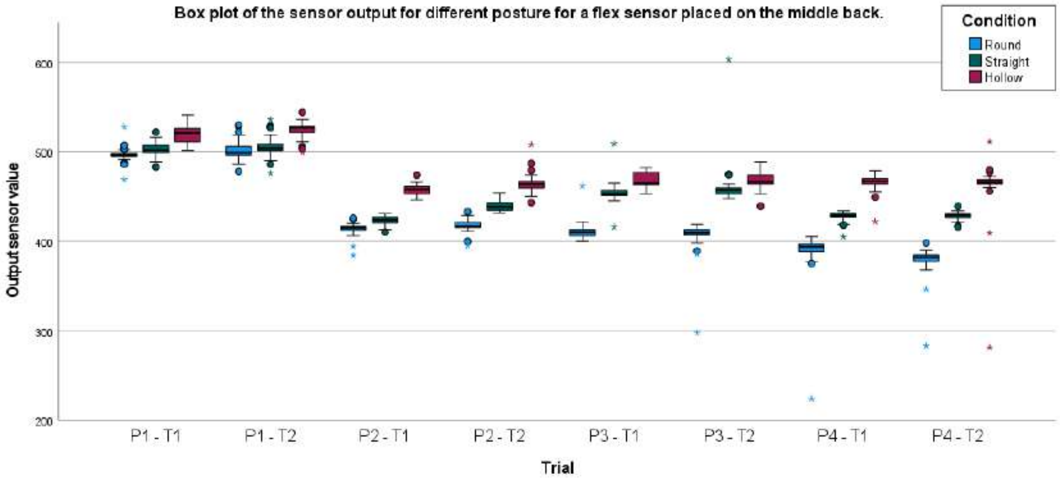


(c) Lower back (d) Full Back

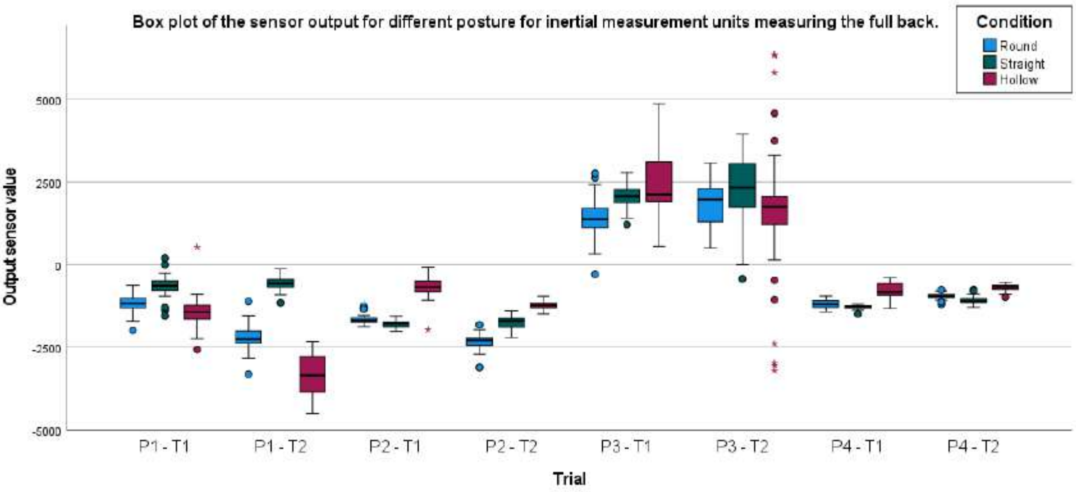
Figure 4.5: Box plots showing the delta for inertial measurement units when placed at different locations.

of the experiment are shown in Figure 4.6.

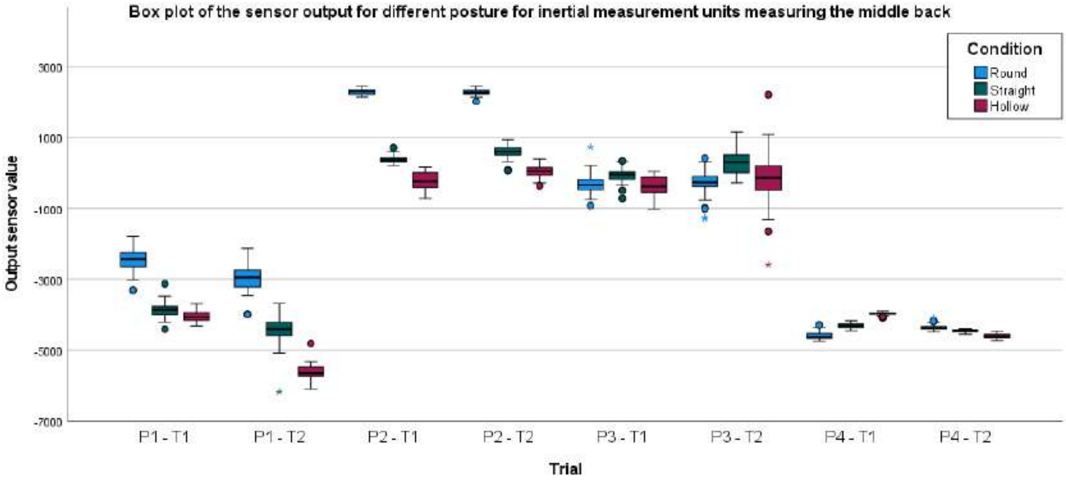
Flex sensors Figure 4.6a shows the range of output values for the different postures when the flex sensor is placed on the middle back. The box plot shows that there is some overlap between the sensor range for a round and straight back for participant 1. This could be caused by the participant not making a completely round back or the participant might not be as flexible as the other participants. For the other participants the sensor data has a different output range for each posture. This means that the sensor can distinguish between a round, straight and hollow back. However, the downside of a



(a) Flex Sensor on the Middle Back



(b) Two IMUs on the back (one upper back and one middle back)



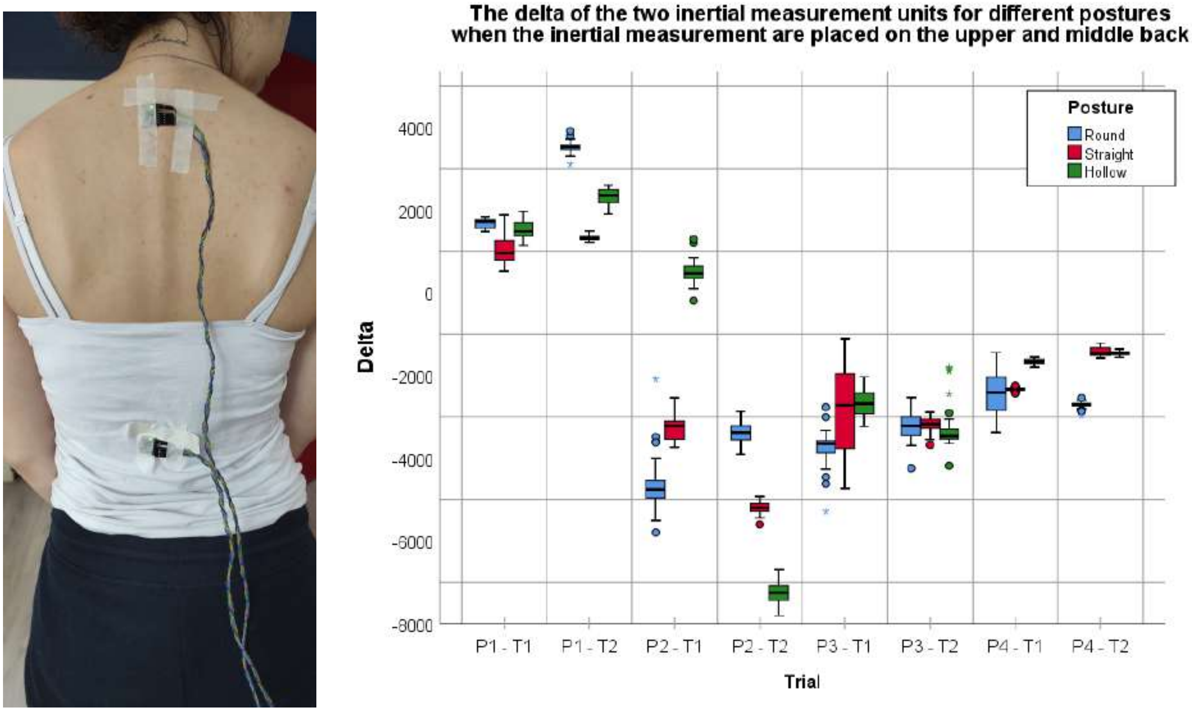
(c) Two IMU on the back (one on the upper back and one on the lower back)

Figure 4.6: The data ranges for different postures and for different sensors and placements. (P1 means participant 1, T1 trial 1 etc.)

flex sensor is that the sensor's precision degrades over time. During the pilot experiment, the flex sensor worked in a range from 0 to 800. During this experiment, the range is reduced to 0 to 600. The loss in precision makes the sensor unsuitable for the project.

Inertial Measurement Unit Figure 4.7b and Figure 4.6c show the results of the placement of IMUs at the middle back and on the full back. When the inertial measurement units are placed on the middle back, the round back overlaps with other conditions during two trials. These two trials are both trials performed with participant 3. For the other trials, the output delta of the sensors do not overlap with other conditions. It is unclear why the values overlap for participant 3 and not for the other participants. It could be that the sensors were placed on slightly different locations or that the participant made a round back differently compared to other users. The round back was made while users were in skating posture, so it could be that the participant moved his upper body more forward or backward compared to other participants.
For inertial measurement units placed on the full back, there is overlap between a round back and other postures in four trials (P1-T1, P2-T1, P3-T2 and P4-T1). The overlap between the round back and other postured happened for all of the participants. This means that this sensor placement cannot determine the posture of the participant based on the delta.

Based on the results of the first test, it was found that IMUs placed on the middle back measure are the best option to measure the curvature of the back. However, the IMUs on the middle show overlap between the values for a round and straight back during one trial. Therefore, it was decided to test one other placement for the IMU. For this placement, one IMU was placed on the upper back and one on the middle back. This was tested with the same 4 participants as the previous experiment. For this experiment, the sensors were taped to the skin except for during the experiment with participant 1 during which the sensors were taped to a shirt. The placement of the sensors and results of the tests are shown in Figure 4.7.



(a) Placement of the IMUs

(b) Results of the measurements

Figure 4.7: The placement of the IMUs in the experiment.

The graph in figure 4.7b shows that there is overlap in the output of the inertial measurement units for a round, straight and hollow back. Considering that this placement does not yield better results than when the IMUs are placed closer together as shown in Figure 4.7b, it was chosen that the best method to determine the curvature of the back is by placing two IMUs on the middle of the back, as shown in Figure 4.3b.

4.1.3 Conclusion

The experiment aims to answer the following questions:

Exp-1.1: ”Where should sensors be placed to accurately measure the curvature of the back?”

Exp-1.2: ”What sensor works best to measure the curvature of the back accurately; inertial measurement units or flex sensors?”

The experiment investigated different types of sensors and sensor placement to measure the curvature of the back. The experiment shows that for both the flex sensor and the inertial measurement units, placement on the middle of the back is most accurate to classify a round back. In the experiment, the long flex sensor showed the least overlap between a round, straight and hollow back compared to IMUs placed on the middle back. However, the flex sensor loses precision over time, which makes the sensor unsuitable for the project. Therefore, the best method to measure the curvature of the back are to use two inertial measurement units which are placed on the middle of the back.

For the experiment, there is a point of discussion. The pilot test was performed with the sensor attached directly to the skin, while for the follow-up experiments the IMUs were placed on the shirt, except for the last measurements (IMUs on the middle-upper back). This could have influenced the accuracy of the measurements, as the placement of the IMUs could change when taped on a t-shirt when the t-shirt slides up or down.

4.2 Experiment 2: Knee angle measurements accuracy

Experiment 2 aims to answer the following research question: *What sensor measures the knee angle most accurate; a flex sensor or inertial measurement unit?*

4.2.1 Method

The context analysis (Chapter 2) showed that to measure a joint angle with inertial measurement units, one sensor should be placed above the joint and one below. Therefore, it was decided to place one IMU on the upper leg and one on the lower leg. The IMUs were placed on the outside of the leg. If the sensor were to be placed on the inside, the sensors would hinder during regular strokes, while sensors at the front or back of the leg could hinder during the crossover. Therefore, the sensors are placed at the outside of the leg. The inertial measurement units are attached to elastic bands which can slide over the participant legs so that the sensors stay in place.

The two inertial measurements are used to measure the difference between the values of the accelerometer along the x-axis. These two values are subtracted from each other to get the difference of the values for the inertial measurement units. This is called the delta. The delta is calculated in the same manner as was done for the back. This formula is shown in Equation 4.1.

The flex sensors could be placed on over the knee or under the knee. Considering many inline skaters wear protection, the top of the knee is not convenient as this is where the knee protection is worn. Therefore, it was chosen to place the flex sensors at the back of the knee. The flex sensors are attached to a knee guard with velcro, so that the sensors stay in place throughout the experiment.

To measure the accuracy of the sensors, the sensor output is compared with manual measurement performed with a goniometer. The subject was asked to make a skating posture with different knee angles. Each time, the angle is measured with the goniometer and compared to the sensor data. This is repeated in steps of 10 degrees for all values between 80 and 180 degrees. The experiment is performed twice.

Before each new test, the sensors are calibrated. This is done by asking a participant to keep a knee angle of 180 degrees for 10 seconds and to make a knee angle of 90 degrees for 10 seconds. The output values of the sensors for 90 degrees and 180 degrees is mapped to a scale from 90 to 180 so that the sensor output is converted to an angle in degrees. The set-up is shown in Figure 4.8

(a) Side view (b) Back view

Figure 4.8: The set-up to measure the accuracy of the sensors. The IMUs were positioned on the side of the upper and lower leg. The flex sensors were attached to the back of the knee using velcro and a knee guard.

4.2.2 Results

The experiment was performed with one participant (male, age: 26). The results of the experiment are shown in Figure 4.9.

The data shows that the short flex sensor is least accurate. The short flex sensor does not register angles above 110 degrees, and outputs a value of 180 degrees for all angles above 110 degrees.
The long flex sensor and IMUs are more accurate as is shown in the graph. To determine which of the sensor is most accurate, the Root-Mean-Square Error (RMSE) for each of the sensor is calculated. The RMSE is a measure to determine the standard deviation of the prediction errors. The RMSE is calculated using the formula described in Equation 4.2.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\text{measured value}_i - \text{actual value}_i)^2}{n}} \tag{4.2}$$

The RMSE for each sensor and each trial is shown in Table 4.1. A lower RMSE means that the sensor is more accurate compared to a higher RMSE value. As the table shows, the IMU is most accurate and has the lowest average RMSE. Therefore, it can be concluded that inertial measurement units are more accurate to measure a knee angle compared to flex sensors.

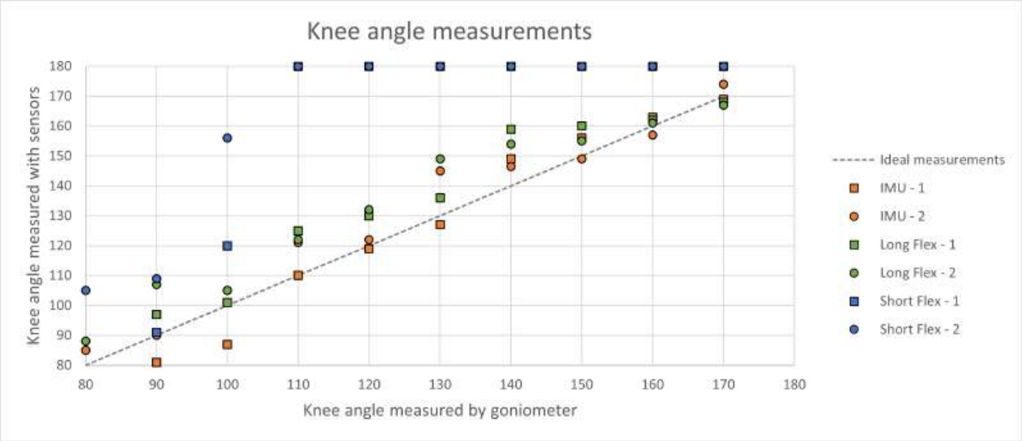


Figure 4.9: The results of the measurements of the knee angle. Trial 1 is displayed with a square and trial 2 with a circle. The grey line shows the situation where the angle measured by the goniometer is the same as the angle measured by the sensor.

Table 4.1: The Root Mean Square Error (RMSE) for the knee angle measurements for the three different sensors.

	IMU	**Long Flex Sensor**	**Short Flex Sensor**
RMSE Trial 1	6,72	10,81	37,96
RMSE Trial 2	6,84	11,22	42,57
Average RMSE	6,78	11,01	40,27

4.2.3 Conclusion

The aim of this experiment was determine which sensor is most accurate to measure the knee angle; flex sensors or inertial measurement units. One participant was asked to make different knee angles and the measured knee angle was compared with the knee angle determined by the sensors. For each of the sensors, the RMSE was calculated. The IMUs had the lowest RMSE which means that those have the highest accuracy to measure knee angle.

There are some points for discussion for this experiment. To measure the knee angle manually, a laser cut goniometer is used, which is less accurate than a regular goniometer. Moreover, as the measurements were done manually it could be that the measurements were a few degrees off. However, the IMUs and flex sensor were worn together, this means that if the goniometer was off, this influenced the measurement for all the sensors. Moreover, the accuracy of the sensor also depends on the posture held during calibration. If the participant did not keep a perfect 90 degree angle, the output of the sensors is off. Therefore, these results can be used to determine which of the three sensors work best to measure a knee angle, but not to determine the accuracy of the different sensors.

4.3 Experiment 3: Durability test

To investigate whether the inertial measurement sensors drift over time and whether the flex sensor loses precision, a durability test was done. For this experiment, the short flex sensor is not tested considering that the previous experiment showed that the sensor is not suitable to measure knee angles accurately. The aim of this experiment is to answer the following question: *"How do flex sensors and inertial measurement units behave over a longer period of time?"*

4.3.1 Method

For this experiment, the sensors were worn during a period of 90 minutes during inline skating. The flex sensor was attached to a knee guard which was worn under knee protection. The IMUs were worn over

Figure 4.10: The set-up for the durability test. The flex sensors are underneath the knee protection.

a sport legging. One IMU was worn on the upper leg and one on the lower leg. The set-up is shown in Figure 4.10.

4.3.2 Results

The durability test was performed by 1 participant (female, age: 22). Throughout experiment 1 and 2, it became clear that the flex sensor lost precision. During the pilot experiment of experiment 1 the long flex sensor output values between 700-800, while for participant 4 in experiment 1, the sensor values degraded to a range between 300 to 500. During this experiment, the sensor range degraded to 0 to 239. This also meant that the sensor became less sensitive to bending. Lastly, the sensor showed deformation, which occurs when the sensors get used for a longer period of time in the same position. The deformation of the flex sensors can be seen in Figure 4.11.

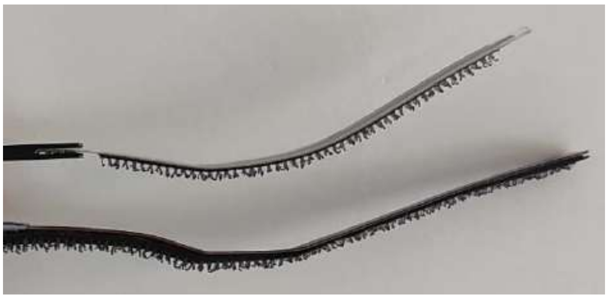
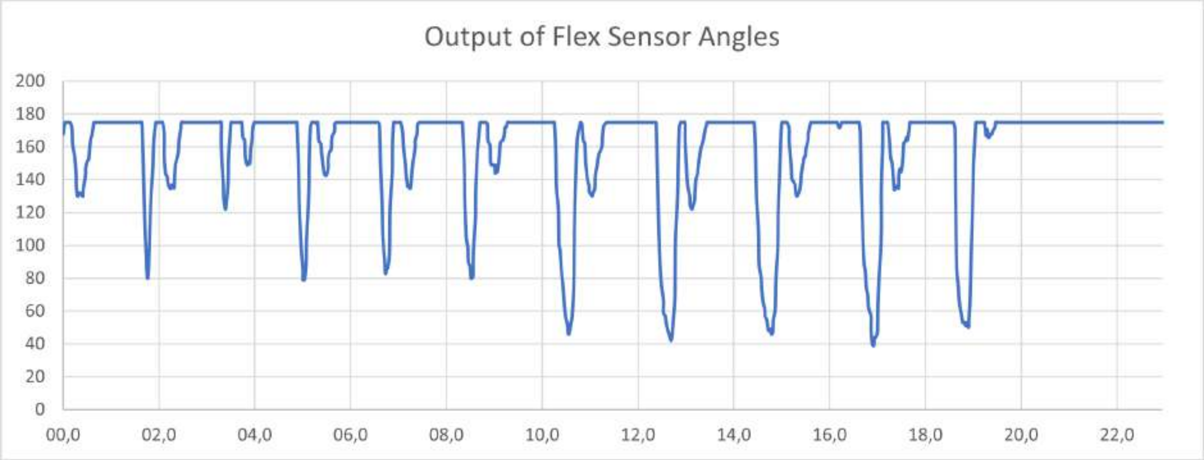
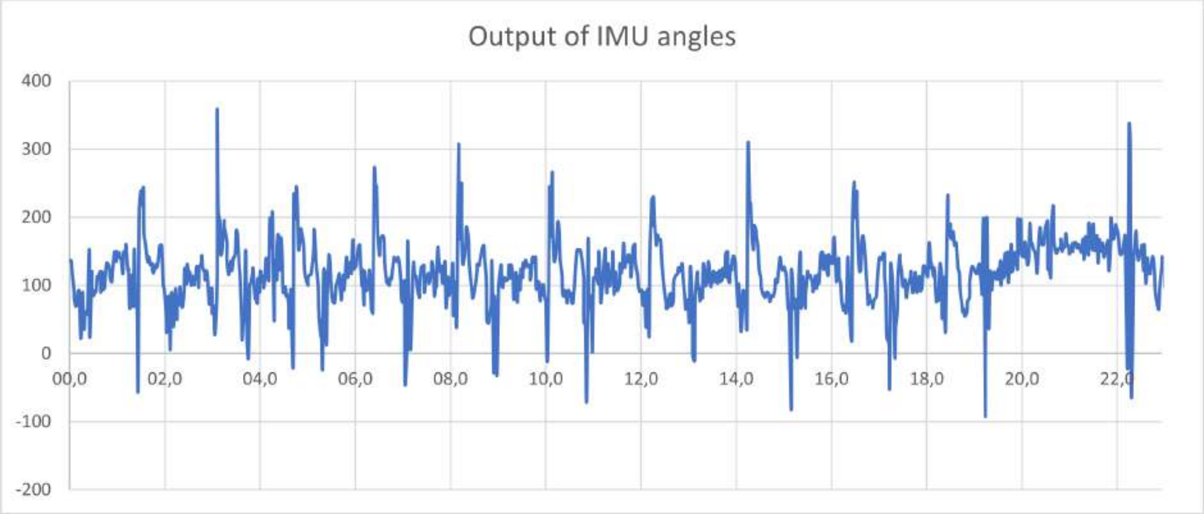


Figure 4.11: The image shows that the flex sensors are deformed throughout the experiments. At the top, the short flex sensor is shown and at the bottom the long flex sensor.

Figure 4.12 shows the measured knee angles with the IMUs and the flex sensors. Due to the loss of precision and deformation, the flex sensor did not detect angles between 150 and 180 degrees. This explains why the graph in figure 4.12a shows many values at 180 degrees.
The IMU is more sensitive compared to the flex sensor. The high peaks (200 - 300 degrees) indicate



(a) Output Flex Sensor. Due to the loss of precision of the flex sensor, the flex sensors often reports 180 degrees.



(b) Output Angle IMU. The peaks of 200 to 300 degrees indicate a push off, while the negative peaks indicate placement of the skate.

Figure 4.12: The results of the sensors over a period of 23 seconds of inline skating. The graphs show that the IMUs are more accurate and sensitive compared to the flex sensors.

a push off and the negative peaks show the moment at which the skate is placed on the asphalt. In between the negative and positive peak is the moment at which the skater glides on one leg. The graph shows that the knee angle ranges from 400 degrees to -100 degrees. The IMUs were calibrated to an angle of 180 degrees and 90 degrees when standing up straight. However, with inline skating, the push is sideways which change the orientation of the IMUs. This means that the mapping of sensor output to angles is incorrect when the skater is not straight above the support leg.

Next, the drift of the inertial measurement unit was investigated by looking at the moving average of the sensor data. The average of 200 data points is taken and plotted in a graph of the raw data. This is shown in Figure 4.13. As can be seen, the moving average stays at the same value throughout the experiment. There are some parts in which the average moves up towards 180 degrees, for example at 0:12. This can be explained as during these periods the skater stood up straight to wait for a traffic light or to rest. Between 1:15 and 1:30, the moving average also moves up. At 1:15, the training ended and some talking was done. Between 1:20 and 1:30, skating was done in positions which alternated straight up skating and skating in the skating posture. This explains why the moving average moves up.

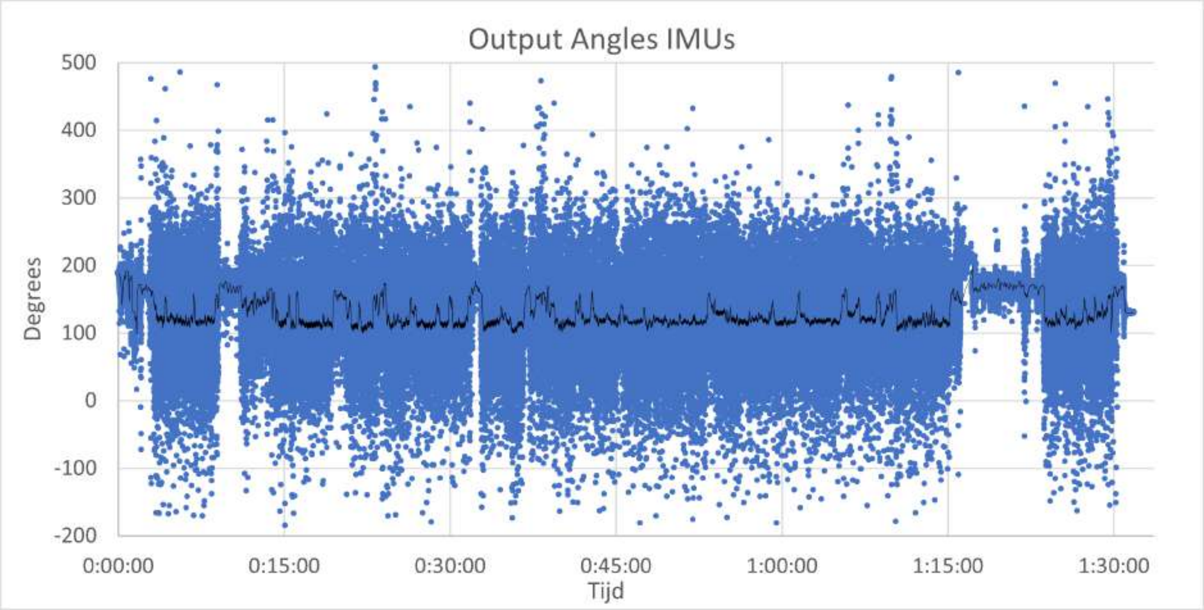


Figure 4.13: The output of the IMU over one and a half hour. The black line shows the baseline of periodic data.

4.3.3 Conclusion

The measurements show that flex sensors are not suitable to measure knee angle during inline skating. The precision of the flex sensor is too low to measure the knee angle accurately. The inertial measurement unit has a higher precision and does not experience drift. This means that the inertial measurement unit is suitable to measure knee angle over a longer period of time.
The experiment also showed that the sensor data is not correctly mapped to an angle if the sensors are calibrated when standing up straight and in the inline skating position, as this calibration does not take into account the sideward movement of inline skating. However, the IMUs are able to measure the knee angle while the user stands on the support leg.

4.4 Conclusion on posture measurements

This section aimed to answer sub question three of the thesis: *How to measure a correct posture in inline skating?* This sub question divided into two sub questions which are answered below;

What sensor works best to measure inline skating posture accurately; flex sensors, inertial measurement units or optical fiber sensors? As optical fiber sensors are not commercially available, this sensor is not used in this project to measure the posture for inline skating. This leaves two sensors; flex sensors and inertial measurement units. Throughout the experiments, it became clear that flex sensors lost precision over time. At the beginning of the experiments, the sensor range was from 0 to 800, while at the end this range was from 0 to 239. The loss in precision made the sensor less sensitive to bending. This made the sensor unsuitable to use over a long period of time and for this project.

This means that the inertial measurement units are the best solution to measure the inline skating posture accurately. Experiment 2 for knee angle accuracy shows that even when the long flex sensor had a high sensitivity, the inertial measurement unit was more accurate to determine the knee angle during stationary movement.

Experiment 3, the durability test, showed that the inertial measurement units can be used to track the knee angle of skating movements as it is possible to see when a skater has pushed off and collected their skate. This information can be used to provide feedback on the knee angle of a skater. Moreover, the experiment showed that the IMUs do not experience drift over the period of one and a half hour, which is a typical length for an inline skating practice.

Where should the sensors be placed to accurately measure knee angle and the curvature of the back? Through literature research it became clear that to measure a joint angle, one IMU should be placed above the joint and one below. This was also done in the experiment and this worked satisfactory to measure the knee angle when the skater is straight above the support leg. During a push-off, the leg moves sideways which makes the measurements inaccurate.

To measure the curvature of the back, five different placements for inertial measurement units wee tested; upper back, middle back, lower back, full back and upper-middle back. Based on the pilot test, three placements were further investigated; (1) one IMU placed on the upper back and one on the middle back, (2) one IMU placed on the upper back and one on the lower back, and (3) one flex sensor placed on the middle back. The results of the experiments showed that the IMUs can best be placed on the middle back, as this gave the least overlap in values between a round back and straight or hollow back.

Chapter 5

Vibration motor placement and Conceptual mapping

Next, the influence of placement of the vibration motors and conceptual mapping was investigated. This is done in two experiments. The first experiment tests different locations for the vibration motors to determine which placement is most intuitive and comfortable.
The second experiment compares focuses on conceptual mapping. The conceptual mapping describes how a vibrotactile signal is interpreted. The user can feel that a signal "pushes away" or "pulls towards" a movement, but the user could also "follow" the vibrations to perform the correct movement. These conceptual mappings are investigated in the second experiment of this chapter.

The designed feedback and the wearable should adhere to requirements. The requirements are stated down below.

- **The vibrotactile feedback should be placed on an intuitive location.**
  The user should link the vibrotactile feedback with a desired instruction. Therefore, the location of the vibration motor should be intuitive to stimulate the user to make a lower knee angle or a round back.
- **The vibrotactile feedback should be placed on an comfortable location.**
  If the placement of the location motors is uncomfortable or hinder movement, there is a possibility that the users will not use the device even if it improves posture. Therefore, the placement of the vibration motors should be comfortable.

5.1 Experiment 4: Motor placement for haptic feedback

During the context analysis (Chapter 2), it became clear that the placement of the vibration motors has an influence on the intuitiveness and reaction time to a trigger. Therefore, the placement of the vibration motors is investigated in this experiment. This experiment aims to answer sub question 4.2:

SQ4.2: What is the best placement for vibration motors to provide intuitive and comfortable haptic feedback?

5.1.1 Method

During the experiment, participants were asked to perform dry skating while haptic feedback was provided to different parts of the legs and torso. Dry skating steps are steps which mimic the the movement of skating (see Figure 5.1). The initial idea was to perform this experiment while participants were inline skating. However, the used vibration motors were difficult to perceive during inline skating and it was undesired to cancel the planned experiments to change to other vibration motors due to time constraints. Therefore, it was decided to test the intuitiveness and comfort of the vibration motor while the participant performed dry skating steps.

During the dry skating steps, feedback was provided once per step when the user was standing on the support leg (see Figure 5.1a) with vibration motors on them. Feedback was provided using a pulse of

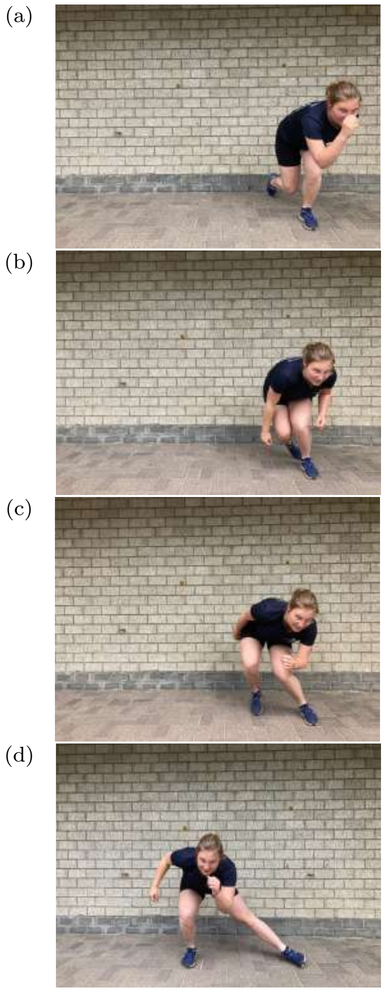


Figure 5.1: The dryskating step. A dry skating step is a step sideways. It starts by (a) standing on the support leg and (b) pushing the hip sideways, so that the skater falls to the side. And (c) during the fall, the skater pushes off with one leg and (d) lands on the other leg with the hip, knees and toe in one line so that the whole weight is directly on the other leg. This is repeated with the left and right leg to mimic skating.

1.5 seconds. This is similar to the duration that a participant rolls on their support leg during inline skating.

To provide feedback on the knee angle of participant, nine different locations were tested. These locations can be seen in Figure 5.2. The vibration motor location were tested in groups of three; upper leg, knees and lower leg. Three vibration motors were attached to an elastic band with velcro. This is shown in Figure 5.3.

The vibration motors are controlled using a ESP32, which was powered with a powerbank. The participants were asked to wear a cycling jersey to the experiment, which is a tight shirt with pockets on the back. The ESP32 and battery were placed in these pockets. The participants were asked to do nine dry skating steps. One motor location was activated for three skating steps each. After nine skating steps, the participants had felt three different locations and were asked to rank the locations on intuitiveness and comfort. This was repeated for the two other groups until all locations were tested. After all nine locations were felt by the participant, the participant was asked to rank all nine locations from most intuitive to least intuitive and from most comfortable to least comfortable. During the ranking, the participants were recorded and asked to think out loud. The order in which the groups and motors in the groups are tested is changed between experiments to avoid bias as people get used to the vibrations.

After the experiment was performed for feedback on the legs, the experiment is repeated for the up-

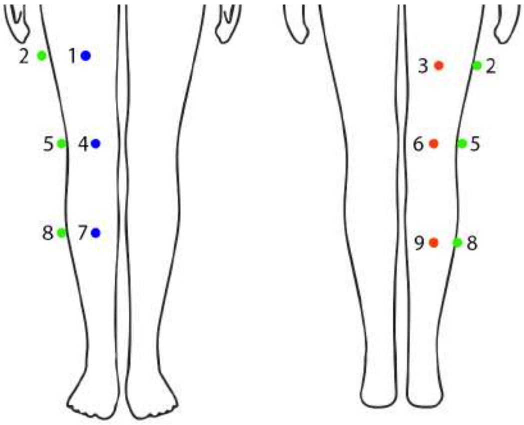
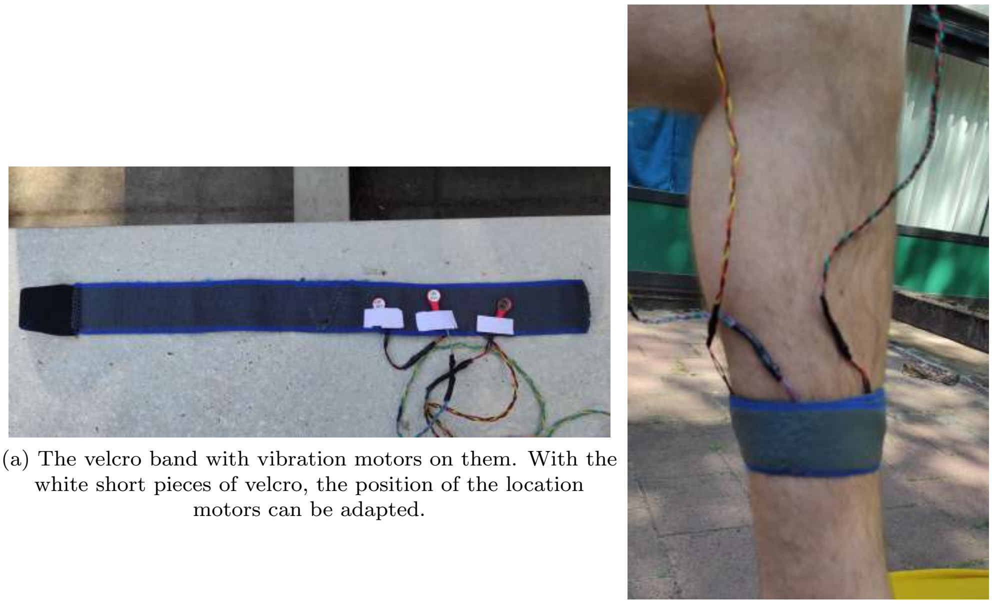


Figure 5.2: The different locations tested to indicate to make a lower knee angle.



(a) The velcro band with vibration motors on them. With the white short pieces of velcro, the position of the location motors can be adapted.

(b) The velcro band attached to the lower leg.

Figure 5.3: The set-up used with the velcro band to test different locations on the legs.

per body to investigate what actuator location is most intuitive for the instruction ”make a round back”. For the torso, six different locations are investigated, which are shown in figure Figure 5.4. The vibration motors are taped to a tight shirt on the desired locations. For the torso, most motors vibrate in pairs. To make a round a back, both shoulders can be pulled in and the spine can move up. Moreover, the pelvis should be tilted backwards. Placement of vibration motors on the spine is uncomfortable [64], therefore it was chosen to place the vibration motors to the left and right of the spine. The different locations are tested in 3 trials; upper torso, middle torso and lower torso. After each trial the participant indicates which location feels most intuitive and comfortable. After 3 trials, the participant is asked to rank all motor locations. Again, during this experiments the order in which motors were changed between participant to avoid a bias if people get used to vibrations. The participants were recorded while ranking the placements to understand why some placements were more intuitive or comfortable compared to others.

5.1.2 Results

Four participants joined the experiment (3 female, 1 male. Age: 21 to 24 (mean: 22,8, median: 23)). The participants were recruited by personally asking members of the student speedskating association

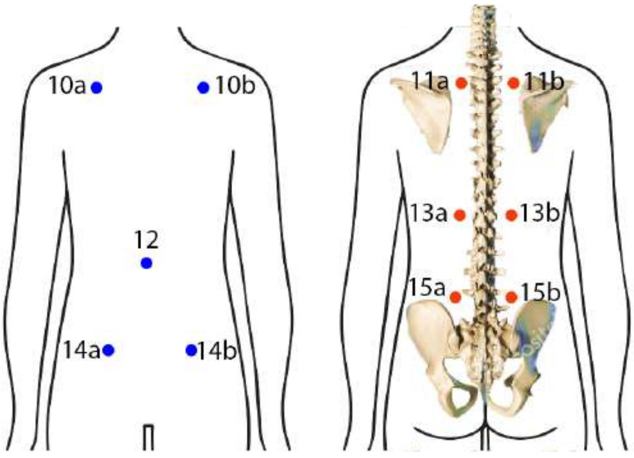


Figure 5.4: The different locations tested to indicate to make a round back.

in Enschede.

Low knee angle

Table 5.1: Top three most intuitive motor placement and top three least intuitive motor placements for the feedback "make a lower knee angle" based on the ranking of the participants.

	P1	**P2**	**P3**	**P4**
Most intuitive motor placements	1. knee - front 2. thigh - side 3. thigh - front	1. knee - back 2. thigh - back 3. lower leg - back	1. knee - side 2. thigh - side 3. knee - front	1. thigh - front 2. thigh - back 3. knee - front
Least intuitive motor placements	1. lower leg - side 2. lower leg - back 3. lower leg - front	1. lower leg - front 2. thigh - front 3. knee - front	1. thigh - back 2. knee - back 3. lower leg - back	1. thigh - side 2. knee - back 3. lower leg - side

Table 5.2: Top three most comfortable motor placement and top three least comfortable motor placements on the legs based on the ranking of the participants.

	P1	**P2**	**P3**	**P4**
Most comfortable motor placements	1. thigh - side 2. thigh - front 3. knee - front	1. lower leg - back 2. thigh - back 3. knee - back	1. thigh - side 2. knee - side 3. lower leg - back	1. thigh - front 2. thigh - back 3. knee - front
Least comfortable motor placements	1. knee - back 2. thigh - back 3. lower leg - side	1. lower leg - front 2. knee - front 3. knee - side	1. knee - back 2. lower leg - front 3. thigh - back	1. lower leg - side 2. knee - side 3. lower leg - front

Table 5.1 and Table 5.2 shows the most and least intuitive and comfortable motor placement based on the rankings of the participants. The transcription of the recordings can be found in Appendix C.

Table 5.1 shows that the participant find the knee and thigh the most intuitive places to get vibrations to remind them to make a lower knee angle.

Table 5.1 shows that many participants find the thigh intuitive to receive feedback for their knee angle. The participants mention the side, front and back of the thigh top three, of which the side and back of the thigh are both mentioned by two participants. Participant 1 and 3 both mentioned that the vibration motor on the back of the thigh gave them the idea that they should move upwards, which was counter intuitive to make a smaller knee angle. Participant 2, on the other hand, felt as if the motor on the back pulled downwards, resulting in a lower knee angle. Participant 4 felt that the motor on the front of the thigh pushed the knee downwards, but also felt that the motor of the back of the thigh could be used to remind a user to make a lower knee angle.

Next to the thigh, the participants found motors on the knee intuitive. Participant 1, 2 and 3 all find vibration motors on the knee most intuitive, but each choose another placement; front, back and side. Vibration motors on the front of the knee can pull the knee forward, while a vibration motor on the back of the knee can push the knee forward, both resulting in a smaller knee angle.

While motors on the knee were intuitive to make a lower knee angle, the users did not agree on whether motors on the knee are comfortable. Participant 1 and 3 both mentioned that motors at the back of the knee were uncomfortable as the band around the knee hindered the participant to make a small knee angle. This might be solved by integrating the vibration motors in the knee guards worn during inline skating. Participant 1 and 4 found vibration motors placed at the front of the knee comfortable.

Next to the knees, the front of the lower leg was also perceived as uncomfortable by 3 out of 4 participants. Participant 2 mentioned that the motor on the front of the lower leg felt a bit "awkward". For the motor on the back of the leg, the participant said: "The back of the leg is a bit softer and then your muscles vibrates along with the motor which gives you the idea that there is something vibrating".

Another interesting finding is that intuitiveness and comfort influence each other. Participant 1 and 3 mentioned found the motor at the back of the knee very uncomfortable since the motor was not intuitive to make a lower knee angle. Participant 3 mentioned; "The motor at the back of the knee is least comfortable because it is on a weird place as it gives me the idea to move up". This shows that intuitiveness and comfort can influence each other.

Based on the results, it can be concluded that the knee and thigh are both intuitive locations to place vibration motors to make a smaller knee angle. Three out of four participants agree that vibration motors placed at the front of the knee are intuitive to make a smaller knee angle. During the design of the wearable, comfort should be taken into account and the wearable should not hinder the users to make a small knee angle.

5.1.2.1 Round back

The results of the rankings for intuitiveness and comfort for the torso to make a round back are shown in Table 5.3 and Table 5.4.

Table 5.3: Top three most intuitive motor placement and the top three least comfortable intuitive placements for the feedback "Make a round back" based on the ranking of the participants.

	P1	**P2**	**P3**	**P4**
Most intuitive motor placements	1. middle back 2. lower back 3. upper back	1. belly 2. shoulders 3. hips	1. hips 2. middle back 3. lower back	1. hips 2. shoulders 3. middle back
Least intuitive motor placements	1. shoulders 2. hips 3. belly	1. upper back 2. lower back 3. middle back	1. shoulders 2. upper back 3. belly	1. lower back 2. shoulders 3. belly

Table 5.4: Top three most comfortable motor placement and top three least comfortable motor placement on the torso based on the ranking of the participants.

	P1	**P2**	**P3**	**P4**
Most comfortable motor placements	1. middle back 2. lower back 3. upper back	1. belly 2. shoulders 3. upperback	1. middle back 2. lower back 3. hips	1. middle back 2. belly 3. lower back
Least comfortable motor placements	1. belly 2. hips 3. shoulders	1. lower back 2. hips 3. middle back	1. belly 2. shoulders 3. upper back	1. hips 2. shoulders 3. upper back

Table 5.3 shows that three out of four participant found vibrations on the middle back intuitive. Participant 1 mentions that the motor on the belly felt ticklish and did not contribute to a better posture, while the motor on the back reminded the participant to pay attention to their back.

Three out of four people found motors placed at the hips intuitive. Participant 2 mentions that the motors on the back caused the participant to straighten its back instead of making it rounder. Participant 4 liked that the motors were placed on the abdominal muscles as the motors reminded them to tighten their abdominal muscles. However, participant 3 mentioned that the motor gets a bit stuck at the belly when making a round back, making the motor less comfortable. Moreover, participant 4 found the motors placed at the hips uncomfortable although the motors did help to improve posture. The participant said: "I think 'Oh the vibration starts again', but the vibration does make my posture better"

Participant 1 mentioned that none of the motors were uncomfortable, but that the motors on the belly were ticklish. Three out of four participants found the motors on the middle back comfortable. Participant 4 mentioned that these motors felt like a massage.

In conclusion, both the motor placement at the hips and back are perceived as intuitive by the participants. However, considering that the motors at the middle back are more comfortable compared to the motors placed at the hips, the motors at the middle back are more suitable for the project.

5.1.3 Conclusion

The aim of this experiment was to answer sub-question 4.2: *What is the best placement for vibration motors to provide intuitive and pleasant perceived feedback?* To investigate this, 9 different locations on the legs were tested to make a lower knee angle and 6 different locations on the torso to make a round back. The experiment was held with 4 participants. The participants were asked which location was most comfortable and intuitive. The experiment showed that intuitiveness and comfort influence each other. Some participants found a motor placement less comfortable if it was not intuitive.

Overall, it was found that to make a lower knee angle vibration motors on the knee or thigh are most intuitive. Three out of four people placed the front of the knee in the top 3 most intuitive locations. Therefore, this location is the best to provide feedback to make a lower knee angle.

For the torso, the middle of the back and the hips are intuitive to make a round back according to the participants. However, the middle of the back was perceived as more comfortable compared to motors placed at the hips. Therefore, it is chosen to create a wearable which provides feedback at the middle of the back.

The next steps are to investigate how a conceptual mapping influences the intuitiveness of the vibrotactile signal.

5.2 Experiment 5: Conceptual mapping

As described in the context analysis, a vibration can "push away" or "pull towards" a motion or a vibration can create a pattern which a person should "follow". The "follow me" mapping is a mapping described by McDaniel et al. [61] as a conceptual mapping in which users follow the direction of the vibration pulses as the vibrations move along the skin.

The aim of this experiment is to investigate which of the three mappings is most intuitive to the participant. The experiment aims to answer the sub-question 4.3:

SQ4.3: What conceptual mapping is most intuitive during skating: "push", "pull" or "follow me"?

5.2.1 Method

Based on the previous experiment, the participants are asked whether they feel that they should "push away" from a vibration or "pull towards" a vibration. The mapping they find most intuitive is compared with the "follow me" mapping. As the results of the previous experiment shows, most participant do have a clear preference for a certain mapping. For example, in the experiment on the legs, participant 1 and 3 did not found the motor placement at the back of the leg intuitive, as this pushed the legs upward instead of down. This means that these participants prefer a ”push” mapping.

For the ”follow me” mapping, McDaniel et al. [61] uses three motors for flexion/extension. Each motor vibrates for four pulses of 100 ms with a 60 ms inter stimulus interval. To attend users that a pattern starts, a longer pulse of 500 ms, with an inter stimulus interval of 200 ms was used, which creates a pattern of 2.56 seconds. The pattern of 2.56 seconds is too long for inline skating as the skater is approximately 1.5 seconds on its support leg. Therefore, the long pulse to get a user's attention was removed and each motor vibrates with 3 pulses of 100 ms instead of 4 pulses. In between the pulses, there is an inter stimulus interval of 60 ms. The length of the ”follow me” pattern to 1.44 seconds. However, during the experiment with the first participant, it was mentioned that the ”follow me” pattern was too slow. Therefore, after the experiment with participant 1, only two pulses were given per motor which reduced the length of the pattern to 0.96 seconds.

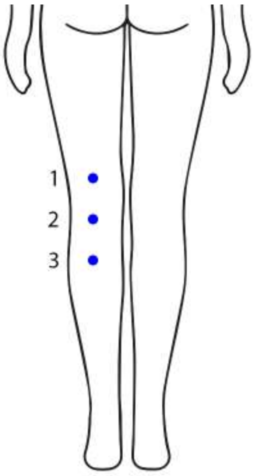


Figure 5.5: The motors are placed at the back of the knee for the ”follow me” mapping. First motor 1 starts pulsing, followed by motors 2 and 3 to create a pattern which the user can follow to make the correct movement.

For the ”follow me” mapping on the legs, a directional pattern in the back of the legs is used with three motors, placed at the back of the leg. One motor is placed 5 cm above the knee, one in the knee cavity and one 5 cm below the knee, as shown in Figure 5.5. This is compared with the preferred actuator placement and mapping of the user.
The ”follow me” mapping is compared to the ”push/pull” mapping of the motor which the participant found most intuitive. The participant were asked to do 6 dry skating steps in which the two conditions are provided during 3 skating steps. Afterwards, the skater is asked which conceptual mapping had a preference.

Unfortunately, McDaniel et al. [61] have not described ”follow me” patterns for the movement of the upper body. Therefore, a ”follow me” pattern was designed. The aim is that the user can follow the vibrations, therefore, two pairs of vibration motors follow each other to indicate the direction of the movement. The pattern corresponds with the pattern for the ”follow me” mapping for the legs. However, as only two motors are used instead of three, four pulses are used were the legs use three pulses. The total duration of the ”follow me” pattern is 1.2 seconds.
The placement and pattern of the motors for the ”follow me” pattern depends on the preferred actuator locations. For the shoulders, motors 11 are followed by 10 (see Figure 5.4), to push the shoulders inward/down. For the middle of the body, motor 12 is followed by 13 to pull the middle of the back backwards. For the bottom pair, 14 is followed by 15 to tilt the pelvis backwards.

As mentioned before, the preferred mapping based on the previous experiment is compared to a ”follow me” mapping. The preferred mapping is asked to the participant with the question: ”You have felt dif-

ferent locations of vibration motors. If you felt a vibration, did you think the vibration location “pulled” towards a movement or “pushed away” from the movement?”
Next, this preferred mapping is compared to the follow me mapping. After both are felt, the following question is asked: ”Which of the two mappings did you find most intuitive? (“Push/Pull” or “Follow me”)” This is performed for both the upper body and the legs. All questions are asked in a semi-structured interview manner. This means that after each question, it was also asked why a participant preferred one mapping over the other and that sometimes follow-up questions were asked. The interviews were recorded and the transcriptions are shown in Appendix D.

5.2.2 Results

Four participants joined this experiment (3 female, 1 male. Age: 21 to 24 (mean: 22,8, median: 23)). Participant 1 and 4 felt that a motor pushed away from a motion, while participant 1 found it most intuitive when a motor pulled towards a movement. Participant 3 mentioned that whether a motor pushed or pulled depends on the location where a motor or placed. At the back of the thigh, the participant felt that the vibration motor pushed away from the movement, but at the front of the knee the motor pulled the knee forward. However, in general this participant mentioned that motors which ”pushed away” were most intuitive.

For the torso to make a round back, there are two ways in which a motor can push away from a motion. For example, the motor in the middle of the back can push the back downwards, decreasing the hip angle, but could also push the back to make a hollow back. Participant 1 mentions about this: ”For the back I felt that a vibration on the middle of the back that I should move towards the vibration to make a rounder back, but for a vibration on my belly I thought that my belly needed more space so that I should move upwards”. This shows that a vibration can be interpreted in different ways depending on the location.

For the legs, most people thought the ”push/pull” mapping was more intuitive compared to the ”follow me” pattern. Three participants mentioned that the ”follow me” pattern was too slow; the top one started vibrating while your on your support leg, but the last one starts when you have already performed a push off. After participant 1, the length of the ”follow me” pattern was decreased from 1.5 to 1 second, while the ”push/pull” mapping still lasted 1.5 second. Although the ”follow me” signal was shorter than the ”push/pull” signal, two participant still mentioned that the pattern was too slow. This can be explained as for inline skating, the feedback should be given just before the push-off as at this moment the knee angle should be smallest. One participant mentioned that the ”follow me” pattern hindered the movement to make a low knee angle, as it was placed at the back of the knee.

For the ”follow me” pattern two participants mentioned that the pattern helped to make a lower knee angle as it is a similar movement as you should do with your legs to make a smaller knee angle. One of these participant thought both the ”follow me” mapping and ”push” mapping could help; ”I think both can help. For a motor on the thigh, I think: ”I have to push my legs down” and for the pattern at the back of the knee I think: ”I need to push my knee forwards”. So they help both. However, personally I prefer the motor on my thigh since for me, pushing my thigh down has more effect on my skating posture than pushing my knees forward.”

For the torso most participants preferred only a ”pull” or ”push” over the ”follow me” mapping. The participant mentioned vibrations on the front and back of the torso were confusing because you had to think more about the vibration as you get vibrations on more locations. Participant 3 preferred the ”follow me” mapping over the ”push” mapping, but also mentioned that the motors on the front were not clearly felt as his t-shirt was not tight to his body during the dry skating steps.

5.2.3 Conclusion

In conclusion, most people preferred the ”push/pull” mapping over the ”follow me” mapping. For the legs, the ”follow me” mapping was too slow, which made the feedback less effective. For the torso, the ”follow me” mapping was more confusing compared to the signal of a single motor, which made the ”push/pull” mapping more intuitive. Most participants believed that a motion should ”push” away from a motor, but this also depended on the motor location.

One point of discussion is that the ”follow me” pattern for the torso was not designed in the study of McDaniel et al. [61]. Therefore, a ”follow me” pattern was designed which consisted of vibrations at the front and back of the torso. Another method to create a ”follow me” signal for a round back would be to place three motors on the back with a signal moving up, which could ”push” the back down to a round back. However, this was not tested in this experiment.

Moreover, the ”follow me” pattern placed at the back of knee, while the ”push/pull” mapping was placed at the location which the participant felt was most intuitive. This means that if a person does not find the back of the knee intuitive, that it is likely that the ”push/pull” mapping is preferred. A better way would have been to test the ”follow me” mapping with a motor placed at the front of the knee and one at the back. Or to compare the ”follow me” mapping at the back of the knee with one single motor at the back of the knee. Therefore, when testing different patterns, directional patterns can be tested to see whether following the signal is more intuitive compared to one signal.

5.3 Conclusion on actuator placement

The aim of this chapter was to answer the research question:

SQ4.2: What is the best placement of actuators to provide intuitive and comfortable haptic feedback?

The experiments showed that to make a smaller knee angle the vibration motor should be placed at the front of the knee as most participant found this location intuitive to get feedback to make a small knee angle. To make a round back, the middle of the back is a suitable location to provide feedback to make a round back. The experiments also showed that a ”push/pull” mapping is more intuitive to make a small knee angle and round back compared to a ”follow me” mapping.

Based on the experiments, it is recommended to create a wearable which does not hinder the user to make a small knee angle which the used band in the experiment did. Therefore, a flexible material could be used or the vibration motor should be integrated in a knee guard, considering that those are already worn during inline skating.

Moreover, the participants mentioned that the ”follow me” mapping for the legs was too slow. Therefore, it is recommended to test different vibration patterns to investigate which patterns are intuitive to the users. This means that the next step is to investigate what patterns are intuitive to improve the inline skating posture.

Chapter 6

Vibration patterns

The previous experiment (Chapter 5) and the context analysis (Chapter 2) show that vibration patterns can influence the intuitiveness of haptic feedback. In this chapter, different vibration patterns are tested to see which patterns are intuitive.

First of all, the vibration patterns should adhere to some requirements. These requirements are:

- **The vibration patterns for should be clear and intuitive to improve posture.** The provided feedback should be intuitive and clear so that the provided feedback stimulates the users improve their posture.
- **The vibration patterns for should be comfortable.** Similar to the location of the vibration motor, the vibration pattern should be comfortable and not hinder movement.

The context analysis showed that different patterns are used in research to provide haptic feedback. Spelmezan et al. [15] used two motors which provide directional instructions to provide feedback in snowboarding. For this, two motors were used where each motor pulsed 2 times for 80ms with 50 ms in between. This creates a pattern length of 470 ms.
McDaniel et al. [69] used a gentle tapping vibration until a desired target angle was reached. For this gentle tapping, vibration pulses of 120 ms on and 120 ms off were used. The feedback was provided on different movements of the hand and arm. According to McDaniel et al. the feedback patterns were found intuitive and coherent between different movement [69].
Lurie et al. [60] investigated different patterns to provide feedback during walking. They found that a single pulse from one single motor was most clear because participant found it difficult to perceive patterns with saltation and patterns that used the same motors in different motions.
Another pattern which can be used is the "follow me" pattern which was also described in Experiment 4. The "follow me" pattern was developed by McDaniel et al. [61] and uses three motors which each pulse sequentially 4 times for 100 ms with a 60 second interval. The aim is to "follow" the vibration to make the correct movement. During experiment 4, it became clear that the follow me pattern was too long and should be below 1 second. Therefore the "follow me" pattern was adapted. Three motors are used, in which each motor pulses twice for 100 ms with a 60 ms interval. This results in a pattern length of 900 ms.

6.1 Experiment 6: Vibration Pattern

The aim of this experiment is to answer SQ4.4.

SQ4.4: What vibration patterns are effective to coach posture in inline skating?

6.1.1 Method

First, the different patterns used in the experiment are described. Afterwards, the set-up of the experiment is discussed.

The vibrotactile feedback should be provided to the support leg between the set-down and the push. The

durability test (Section 4.3) showed that the time between the set-down and push off is approximately 1 second, which means that that the pattern length should be maximum 1 second. Based on patterns used before in literature, a list of patterns is created which are tested to see which pattern is most intuitive to make a lower knee angle and to make a round back.
There are four types of patterns:

- Single Pulse (SP), is a single pulse of 1 second provided by 1 motor.
- Gentle tapping (GT), which is 4 times a pulse of 120 seconds on and 120 seconds off.
- Directional Pattern (DP), which is a directional pattern of two vibration motors. Each vibration motor vibrates three times for 100 ms, with an interstimulus interval of 50 ms.
- Follow me (FM), is a directional pattern which uses three vibration motors. Each vibration motor vibrates twice for 100 ms with an interval of 60 ms.

For feedback to the knee, three motor locations were used. The motor locations are shown in Figure 6.1a. Below, the different patterns tested in the experiment are listed.

1. Single pulse for motor 2.
2. Single pulse for motor 3.
3. Gentle tapping for motor 2.
4. Gentle tapping for motor 3.
5. Directional pattern with motor 1 and 2.
6. Directional pattern with motor 2 and 3.
7. Follow me with motor 1, 2, 3.

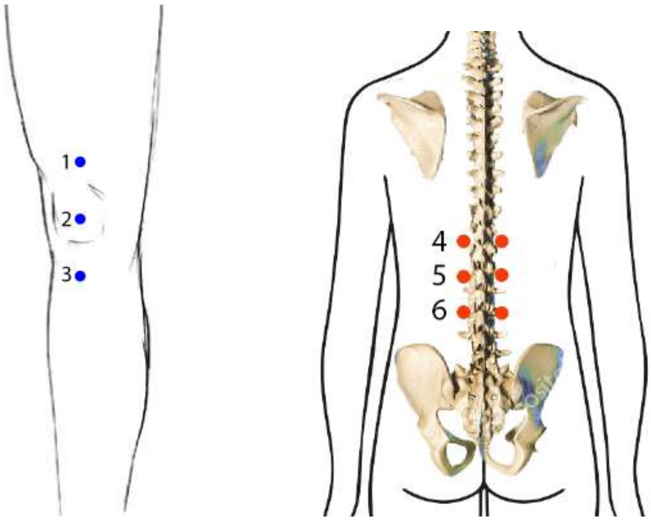
On the back, three different motor locations were tested which are shown in Figure 6.1b. The motors vibrate in pairs where one motor is placed on one side of the spine and the other on the other side. Below, the different patterns which are tested are listed.

1. Single pulse for motor 5.
2. Gentle tapping for motor 5.
3. Directional pattern for motor 6 and 5.
4. Directional pattern for motor 5 and 4.
5. Directional pattern from motor 4 to 5.
6. Directional pattern from motor 5 to 6.
7. Follow me with motor 6, 5 and 4.
8. Follow me with motor 4, 5 and 6.

The patterns are tested while the participants are inline skating. The vibration motors are taped to the participant, after which the participant is asked to skate one lap to see if the motors and wires are comfortable and do not hinder movement. If this is not the case, the participant is asked to skate two laps. During the first straight, no patterns are activated yet, but during the second and third straight two different patterns are tested during the whole straight end. During each trial, 2 to 3 patterns are tested. After the laps, the participant is asked to rank which pattern was most comfortable and which pattern was most intuitive. This is repeated three times for the legs, so that all patterns are felt. Afterwards, the user is asked to rank the patterns based on comfort and intuitiveness.

This is repeated for the torso. For the torso, first one round is skated to get used to the motors. Afterwards 4 times 1.5 round is skated. In each session of 1.5 rounds, 2 patterns are tested. At the end, the user is asked to rank the patterns based on intuitiveness and comfort.
After the experiment, a small interview is held with the users to get their opinion on the feedback and to find points of improvement. The following questions are asked:

1. What do you think about the feedback?
2. What would you change about the feedback?
3. What did you think of the lengths of the patterns?
4. How often would you like to get feedback on posture?



(a) The placement of the motors on the knee.

(b) The placement of the motors on the back

Figure 6.1: The placement of the different motors during the pattern tests.

6.1.2 Results

Four participant joined the experiment. Two participants were male and two female. The participants were between 22 and 24 years old (mean age: 22.75, median: 22.5). Based on the ranking of the patterns, each pattern was scored. The most intuitive pattern scores 1 point, the second most intuitive 2 points and so on. This means that the lowest scoring pattern is most intuitive according to the participants. The same scoring was applied for the most comfortable motor.

Low knee angle

The results of the ranking of the patterns can be seen in Table 6.1 and Table 6.2.

Table 6.1: The scores on intuitiveness for different vibration patterns to make a low knee angle.

Intuitiveness	**P1**	**P2**	**P3**	**P4**	**Total**
Pattern 1	3	1	6	2	12
Pattern 2	2	2	1	3	8
Pattern 3	7	7	7	7	28
Pattern 4	6	4	2	6	18
Pattern 5	1	6	5	1	13
Pattern 6	4	5	4	5	18
Pattern 7	5	3	3	4	15

Table 6.2: The scores on comfort for different vibration patterns to make a low knee angle.

Comfort	**P1**	**P2**	**P3**	**P4**	**Total**
Pattern 1	3	1	6	2	12
Pattern 2	2	2	1	3	8
Pattern 3	7	7	7	5	26
Pattern 4	6	4	2	4	16
Pattern 5	1	6	5	1	13
Pattern 6	5	5	4	7	21
Pattern 7	4	3	3	6	16

The tables show that pattern 2 scores lowest on both intuitiveness and comfort. Pattern 2 is the single pulse pattern with motor 3, which is the motor positioned underneath the knee. The scores for intuitiveness and comfort are very similar. Participant two mentioned: "Comfort is influenced by intuitiveness as none of the motors hinder movement or are uncomfortable" and therefore chose to rank the motors for comfort exactly the same way as intuitiveness.

The tables also show that pattern 1 and 2 have the lowest scores, which are both single pulse patterns. The participants found that the single pulse patterns were short and easy to feel. Participant 2 mentioned that the pattern was short and clear making them a good reminder to make a lower knee angle.

The lowest scoring pattern for both intuitiveness and comfort is pattern 3, which is the a gentle tapping pattern on the knee. Participants mentioned that the motor on the knee was difficult to perceive or was perceived as ticklish.

Two participant suggested new patterns. According to participant 1, the best signal would be a single pulse with motor 1. Participant 3 suggested to do a single pulse with motor 1 and 3 combined to trigger vibrations around the knee to indicate to make a lower knee angle.

Round back

Table 6.3 and Table 6.4 show the scoring of the intuitiveness and comfort of the patterns on the torso. The ranking for intuitiveness and comfort are similar to each other as was also the case for the low knee angle.

Table 6.3: The scores on intuitiveness for different vibration patterns to make a round back.

Intuitiveness	**P1**	**P2**	**P3**	**P4**	**Total**
Pattern 1	6	1	1	8	16
Pattern 2	5	2	8	7	22
Pattern 3	7	6	6	6	25
Pattern 4	8	7	2	5	22
Pattern 5	1	4	4	2	11
Pattern 6	2	5	7	3	17
Pattern 7	3	8	5	1	17
Pattern 8	4	3	3	4	14

Table 6.4: The scores on comfort for different vibration patterns to make a round back.

Comfort	**P1**	**P2**	**P3**	**P4**	**Total**
Pattern 1	6	1	4	8	19
Pattern 2	5	2	8	7	22
Pattern 3	8	6	6	5	25
Pattern 4	7	7	1	6	21
Pattern 5	1	4	3	2	10
Pattern 6	2	5	7	3	17
Pattern 7	3	8	5	1	17
Pattern 8	4	3	2	4	13

The tables show that pattern 5 has the lowest score on intuitiveness and comfort compared to the other patterns. Pattern 5 is the directional pattern from motor 4 to 5. Participant 1 mentioned about pattern 5: "When I felt this pattern, I immediately thought: 'this is it!', I found this pattern most intuitive and comfortable".

The opinion on pattern 1 are very mixed. Two participants placed the signal on most intuitive pattern, while the other two participants placed the pattern on place 6 and 8. Participant 4 mentioned that the single pulse made the participant think that a phone was vibrating, considering that phones during inline skating are often worn in a pocket on the lower back. Therefore, the participant did not associate this pattern with an instruction to make a round back.

The least intuitive and comfortable pattern was pattern 3. This pattern is a directional pattern from motor 6 to 5. Participant 3 mentioned that pattern 3 was difficult to perceive and participant 1 was startled by the pattern each time it started.

Interviews

After the experiment, a small interview was held with the participants. The transcription of the interviews is shown in Appendix E.

In the interview, the participants mentioned that the feedback was good. However, there were also some improvements. Two participants mentioned that the feedback should be given to the support leg before the push off, as feedback during the push-off did not feel intuitive. Moreover, one participant wondered whether feedback at both legs, one after another might feel complex during inline skating.

The participants were asked how often the feedback should be given. The participants agreed that the feedback should be given when the posture is incorrect and that it could be given for a couple of strides, so that there is some time to adapt to the feedback. One participant mentioned that the feedback could continue until the posture was correct. However, if feedback was given continuously, some participants thought you could get used to the feedback, which makes it less effective. Two participants mentioned that it could work frustrating if you get feedback while doing the posture correctly so that should be avoided.

The length of the patterns was good according to the participants. The participants mentioned that the pattern was useful considering that the pattern was shorter than one stride.

One participant mentioned that advanced inline skaters do not wear protection while inline skating. This means that the knee guard with vibration motors might be worn less. To overcome this, it could be possible to make smaller knee guards or make small motor patches which can be worn by advanced inline skaters.

6.1.3 Conclusion

The aim of the experiment was to answer research question SQ4.4;

SQ4.4: What vibration patterns are effective to coach posture in inline skating?

Based on the experiments, it can be concluded that a single pulse pattern below the knee is the most intuitive pattern to make a smaller knee angle. This pattern was ranked highest by the four participant who tested it during inline skating. For the torso, a directional pattern from the upper back to the middle back is most intuitive to make a round back.

Both the pattern for the torso as the pattern for the knee were perceived as the most intuitive and most comfortable patterns out of the patterns tested. For the knee, two participant suggested a pattern which was not tested in this experiment. These patterns could be tested in another research to see if these patterns are more comfortable and intuitive compared to the tested patterns in these experiments.

Chapter 7

Realisation

The experiments performed in chapter 4, 5 and 6 provided insights to how the created wearable could be designed to fulfil all requirements. Moreover, the experiments led to some new requirements. Here is the full list of requirements that the wearable should adhere to.

1. **The system should be able to measure posture during inline skating.**
   In Chapter 4 experiments were performed to determine how the inline skating posture can be measured. The experiments in Section 4.1 and Section 4.2 show that inertial measurement units can be used to measure the inline skating posture. To measure the posture of the back, the IMUs should be placed on the middle of the back. To measure the knee angle, one IMU should be placed above the knee and one IMU should be placed below the knee.
2. **The system should provide intuitive and comfortable feedback.**
   Chapter 5 and Chapter 6 investigated the design of intuitive vibrotactile signals to improve the inline skating posture. The experiments found that an intuitive signal to make a lower knee angle is one single pulse positioned at the front of the knee.
   An intuitive signal to remind the user to make a round back is to use a directional pattern with two pairs of vibration motors positioned on the middle back. The pattern moves down over the back.
3. **The system work continuously for at least for 1.5 hours.**
   The durability test in Section 4.3 showed that the inertial measurements units are able to measure the knee angle accurately for 1.5 hour without experiencing drift. The used batteries and hardware should also be able to last up to 1.5 hours.
4. **The wearable should not hinder the movement of the inline skater.**
   In Section 5.1 a band was used to attach the vibrations motors to. The participants mentioned that this hindered them to make a lower knee angle and was uncomfortable. Therefore, it is important that the wearable does not hinder movement.
5. **The provided feedback should be effective to improve the inline skating posture.**
   The aim of the research is to create a wearable which improves inline skating posture. Therefore, the wearable should be effective to improve the posture.

Based on the requirements and knowledge gained throughout the experiment, the wearable was designed. This chapter describes how the wearable was developed.

7.1 Hardware

The hardware of the wearable consists of an ESP32, a battery pack, vibration motors and inertial measurement units. In this section, each of the components are explained.

7.1.1 ESP32

The ESP32 Featherboard is used as a micro controller. The ESP32 has built-in WiFi and Bluetooth. It provides 3.3 V and can be charged using external batteries. During this project, a battery pack containing 4 batteries of 1.5V in series was used. The 4 batteries provided the vibration motors enough power to give strong vibrations. The batteries lasted approximately 7.5 hours. The ESP32 was programmed using the Arduino IDE. The board is connected to a mobile phone via Bluetooth. Using Bluetooth, all the data from the ESP32 is send to the mobile phone. The mobile phone logs all the sensor data so that it can be read out later.

7.1.2 Vibration motors

Three different vibration motors were used throughout the experiments in the chapters 4, 5 and 6. These motors are shown in Figure 7.1. First, two types of coin type vibration motors were used, but these were difficult to perceive during inline skating. The second coin motor was stronger compared to the first one, but still difficult to perceive during inline skating. Therefore, larger cylindrical motors were used considering that these are more powerful compared to the coin motors. At first, these motors were used in combination with a transistor and a 10k resistor. The 10k resistor provided a too large voltage drop which reduced the power of the cylindrical motor. The 10k resistor was replaced by a 1k resistor. The cylindrical motors with a 1k resistor were powerful enough to perceive during inline skating on smooth asphalt. However, not all participants felt the cylindrical motors clearly when placed on the knee cap. On the torso, the cylindrical motors were generally perceived well. Therefore, it was decided to use the cylindrical vibration motors in the final prototype. The vibration motors were put into a 3D printed casing to protect the rotating part of the vibration motors. The motors were powered by the batteries which also power the ESP32.

Figure 7.1: The three vibration motors which were used throughout the experiments. The vibration motors are ordered from left to right on vibration strength. The first two coin motors were too weak to perceive during inline skating. The cylindrical motor can be perceived during inline skating.

7.1.3 Inertial Measurement Units

Chapter 4 showed that inertial measurement units are the best sensors to measure the posture. To measure the knee angle, four inertial measurement units are used. Two for each leg, where one inertial measurement unit is placed on the upper leg and one on the lower leg. Both IMUs are placed on the outside of the leg, as this location provides the least hinder during inline skating. Sensors on the front and back of the leg could hinder the skaters during crossover steps, while sensors at the inside of the leg hinders during a regular stride. To measure the curvature of the back, two inertial measurement units are used which are placed on the middle of the back.

For the inertial measurement units, the MPU6050 inertial measurement unit is used, which consists of an accelerometer and a gyroscope. The MPU6050 supports two addresses 0x69 and 0x68. To communicate with six IMUs, all IMUs are set to one address (0x69). To listen to one IMU, the address of this IMU is set to 0x68. This way, the program can loop through all IMUs and listen to them one at a time.

For each part of the posture (left leg knee angle, right leg knee angle, and curvature of the back) two IMUs are used. The difference between the values of the accelerometer for the x-axis for both IMUs measuring one part of the posture are used to determine the posture. This value is the delta. The delta is computed with the following equation:

$$\text{delta} = \text{accelerometer}_1.x - \text{accelerometer}_2.x \tag{7.1}$$

Three delta values are used to define the posture. This is the delta for the left leg, delta for the right leg and the delta for the back. The placement of the inertial measurement units can be seen in Figure 7.2.

(a) IMUs placed on the right leg. One IMU is placed above the joint and one below. Underneath the knee guard, the vibration motor is placed.

(b) IMU placement on the back to measure whether a person has a round back or not. The four white clips are where the vibration motors are positioned.

(c) Full setup from the back. On the right shoulder, a motor for a 'pat on the back' is located.

Figure 7.2: The placement of the inertial measurement units and vibration sensors for the wearable.

The IMUs need to be calibrated to get information on the correct posture for inline skating. Therefore, four calibration steps are performed. The steps contain of four postures which the participant should hold for 10 seconds. In between the steps is a 5 second break in which the participant can change from posture. Below, the four calibration steps are written down.

Step 1: Make a knee angle of 90 degrees.

Step 2: Stand up straight.

Step 3: Make the knee angle which is desired to keep during the inline skating session. Based on this knee angle, feedback is provided to the user.

Step 4: Make a round back while being in the skating posture.

The first two calibration steps are used to map the delta value of the inertial measurement unit to a knee angle. These steps provide an average delta value for both legs which correspond with an angle of 90 degrees and an angle of 175 degrees, which can be mapped to the knee angles. The third calibration step is done to determine the knee angle which the system regards as "too high" . If the average knee angle of the participant is higher than this angle, negative feedback is provided. The fourth step measures the round back. Based on the measured output during the calibration phase, the minimum and maximum values for a correct posture are determined. The user should keep the posture of the back between these values, otherwise negative feedback is provided.

The complete hardware set-up is shown in the schematic in Figure 7.3.

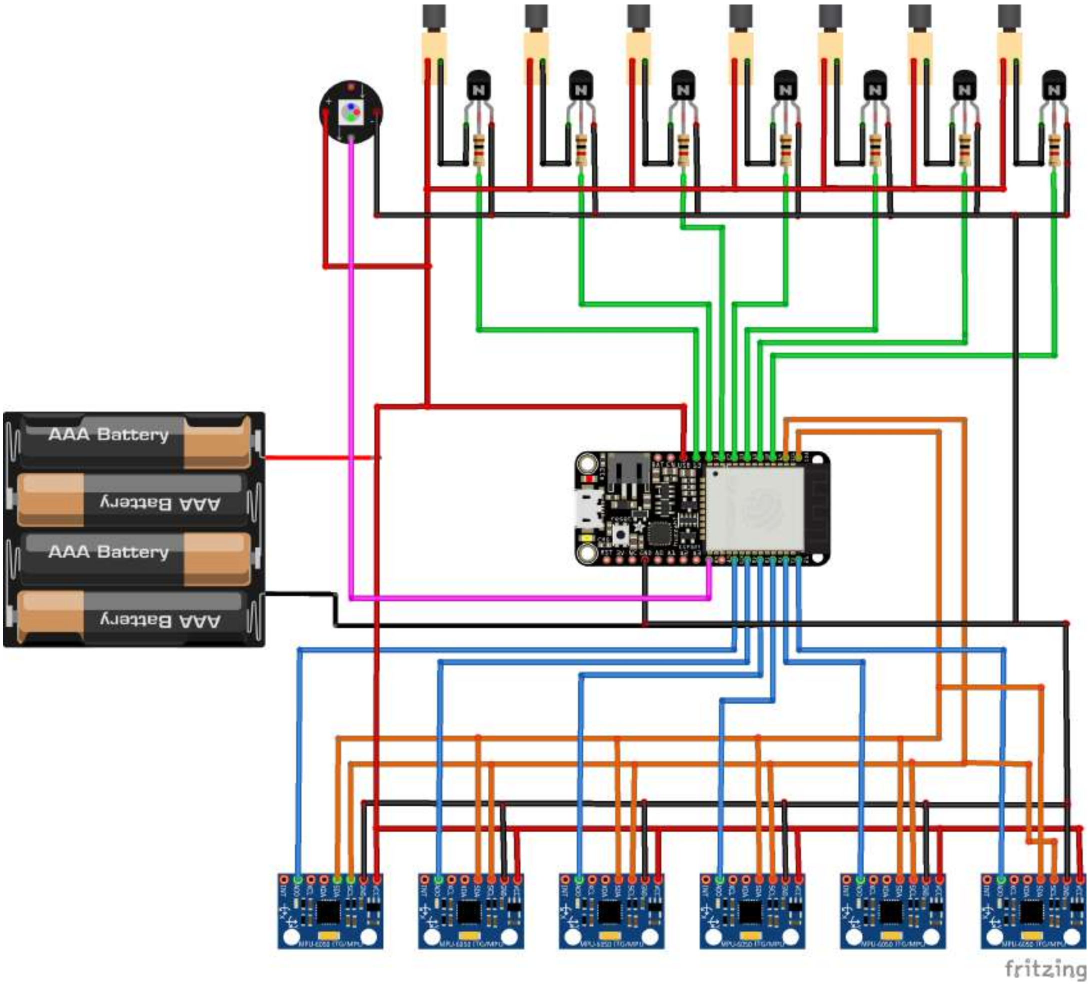


Figure 7.3: A schematic of the hardware used in the wearable.

7.2 Feedback design

Based on the experiments in Chapter 5 and Chapter 6, the feedback locations and patterns for the negative feedback were selected.

For the knees, the software checks each six strides whether the knee angle is too high. If the knee angle is too high for four out of six strides, negative feedback is provided. The negative feedback consists of a pulse below the knee of the support leg. The pulse is given for four strides. This means that the participant feels four pulses. The software alternates between the left and right leg so that two pulses are given to the left leg and two pulses are given to the right leg.

For the back, four different motors are used. The four motors create a directional pattern from the upper middle back to the middle back. First, the upper two motors pulse three times, followed by the lower two motors. The pulses last for 100 ms with an inter-stimulus interval of 100 ms. The placement of the motors can be seen in figure 7.2b.

Lastly, a positive feedback signal was created. The positive signal was created to motivate the users and to indicate that the system is still working when a user does not receive negative feedback.
For the positive feedback signal, one vibration motor was placed to at the back of the shoulder to give a 'pat on the back' when the skating posture was correct. The pat on the back consist of three pulses of 100 ms with an inter-stimulus interval of 50 ms. The placement of the motor is shown in figure 7.2c.

The wearable contains of four modes; it can provide feedback to the back, to the knee, to both or not feedback at all. If the wearable provides only feedback to the back or knee, feedback is given every

30 seconds. When negative feedback is provided, a positive feedback signal can be given after 10 seconds if the participants improved its posture. After a positive feedback signal, no feedback is given for 30 seconds. It takes approximately 1 minute to skate one lap on a 400 meter track. This means that the participant receives feedback approximately twice per lap.

7.3 Wearable development

The wearable was developed by incorporates all the electronics and designing a harness. During the experiment on posture measurement in Chapter 4 the inertial measurement units were mounted to elastic bands. The downside of these bands is that they should slide over the leg to wear them. This is inconvenient when a person is already wearing skates. Therefore, elastic velcro bands were used. These bands could be wrapped around the leg. The vibration motor was placed underneath the knee guard of participants, so that the participant could skate with their own knee guards on. If a participant did not wear knee guards, the vibration motor was taped to the knee of the user.

For the feedback on the back and shoulder and the IMUs on the back, a harness was created. The harness consists of a fanny pack in which the electronics could be placed. Attached to the fanny pack are two elastic bands which go over the shoulders. The harness can be tightened on the front side, so that the motors and IMUs are against the back of the user. The harness can be seen in Figure 7.2c.

Chapter 8

Evaluation

An evaluation test was performed to determine if the created wearable is effective to improve the posture during inline skating. The aim of the test is to answer the question: ”Is the designed wearable effective to improve posture during inline skating?” The method and results of the evaluation test are discussed in this chapter.

8.1 Method

The experiment consists of two parts. The experiment itself and an interview.

8.1.1 Experiment

In the experiment, users were asked to skate laps while wearing the wearable. The wearable measures the knee angle and curvature of the back, while also providing feedback to the knees and back when the measured posture. For the experiment, participant were recruited from the student skating association in Enschede. The participant should be of intermediate or advanced level to minimise the risk of falling during the experiment.

Before the experiment, the users filled out a consent form (Section B) and put on the wearable. Next, calibration took place. For the calibration, the participants were asked to make four postures, as was discussed in the previous chapter. These postures are: 1) make the inline skating posture with a knee angle of 90 degrees, 2) stand up straight, 3) make the inline skating posture with a knee angle the participants want to skate in for four minutes and 4) make the skating posture with a round back. For the first pose, a goniometer was used to measure whether the participants made a knee angle of 90 degrees.

The participant were asked to skate 5 times four minutes with a four minute rest period in between. For all sessions, the skaters were instructed to make a low knee angle and a round back. To avoid bias as people get used to vibrations, there were two different orders in which the users received feedback. The two orders are shown in Table 8.1.

Table 8.1: The conditions for each of the trials during the user test. There are two orders to avoid bias.

	Order 1	Order 2
Trial 1	No feedback	No feedback
Trial 2	Feedback knees	Feedback back
Trial 3	Feedback back	Feedback knees
Trial 4	Feedback knees and back	Feedback knees and back
Trial 5	No feedback	No feedback

During the first trial, the users received no feedback. This is the baseline trial to which the other trials are compared. During trial 2 and 3, feedback is provided separately to the knees and back, so that the participants could get used to the feedback. For trial 4, feedback is provided to both the knees and back at the same time. Trial 5 is another trial without feedback. This trial is used to see whether fatigue or learning influenced the measurements.

If after trial 2 or 3 was noticed that the participant only received positive feedback or only negative feedback, the desired knee angle was adapted before trial 4, so that the desired knee angle was suitable for the skater. This was done considering that only positive feedback does not stimulate the user to make a lower knee angle and only negative feedback can demotivate the participant.

Most of the experiments took place on the UTrack. However, if the UTrack was unavailable or participants were not able to come to the UTrack, other locations were selected. The preferences for locations were locations where laps could be skated on smooth asphalt. These locations were found at Combibaan Hengelo and a parking lot. The UTrack, Combibaan Hengelo and the parking lot have similar asphalt. The UTrack and Combibaan Hengelo are both 400m tracks, but the UTrack has wider corners compared to Combibaan Hengelo. The lap at the parking lot is also approximately 400 meter, but this lap has a longer straight end (approximately 140m) and a sharper corner compared to the UTrack.
Participant 17 and 18 were not able to come to a location where laps could be skated so these tests were held on straight ends. The straight end was long enough for the skaters to skate 4 minutes non-stop.

The study is a within-subject study. The posture of a participant in trial 1 is compared to the posture in the other trials. This means that even though different locations are used, it is still possible to determine whether the posture of inline skater improved over the trails as the conditions of the experiment for one participant remained the same throughout the trials.

Data Analysis

Throughout the experiment, the sensor data was send to a telephone using Bluetooth. The recorded data was split in five groups; one for each of the trials. The data of each trial was put into its own excel sheet. Next, a python script was written which could analyse the data. The script detects peaks in the data. Each peak in the data indicates a push-off. When a person pushes off with the right leg, the left leg becomes the support leg until a push-off is performed with the left leg and vice versa. This makes it possible to calculate the average angle of each support leg.

The peaks are detected using the function `scipy.signal.find_peaks()`. This function finds all the local maxima by comparing the data to its neighbours. To ensure that the correct peaks were taken, three extra parameters were used; height, prominence and distance. First, the peak should be at least 10 degrees above the mean angle of one trial to eliminate peaks which occur due to placement of the inline skate. Second, the prominence should be above 70. The peak prominence is the vertical distance between the peak and the lowest contour line. It describes how much a peak stands out from the surrounding baseline of the signal. The peak prominence is a useful parameter to discard small peaks compared to the baseline. Third, the distance between to peaks should at least be 20 data points. This eliminates peaks which follow each other too closely.

The python script uses the detected peaks to calculate the average angle and to calculate the number of strides. The strides are an extra measure to see whether the peak detection is done correctly. If the peak detection detects too many peaks, the number of strides is high while if the peak detection detects too few peaks, the number of strides is low.
Based on the average number knee angle, statistical tests can be performed to investigate whether the wearable helps to improve posture during inline skating or not. The statistical tests which are performed is a repeated measures ANOVA and a Sign Test. This is explained in subsection 3.2.2.

8.1.2 Interview

After the experiment, a small interview was held with the participants. This interview was audio-recorded. During the interview, the following questions were asked:

1. What did you think about the feedback?
2. Do you think that the feedback improved your posture?
3. Would you use the wearable during inline skating?
4. What did you think about the feedback on the knee angle?
5. What did you think about the feedback on the curvature of the back?

6. What would you change about the wearable?

8.2 Results

The experiment was performed with 18 participants. An overview of all the participants can be found in Table 8.2. Not all experiments went as expected, which is why not all data is used in the statistical analysis. The IMUs measuring the knee angle of participant 3 slid down during the tests, which makes the data inaccurate. For participant 16, the first two trials were not logged correctly for both the knee angle and back. This leaves 17 suitable data sets for the posture of the back and 16 for the knee angle.

Table 8.2: An overview of the gender, age and experience level of the participants in the evaluation test. [1]Data not suitable for knee angle. [2]Data not suitable for back.

Participant	Gender	Age	Experience	Condition	Trial Length	Location
1	F	23	Intermediate	1	4 min	Parking lot
2	F	25	Advanced	2	4 min	Parking lot
3[1]	F	24	Intermediate	1	4 min	UTrack
4	M	22	Intermediate	2	4 min	UTrack
5	M	26	Advanced	1	4 min	UTrack
6	M	22	Advanced	2	4 min	UTrack
7	F	19	Advanced	1	4 min	UTrack
8	F	24	Advanced	2	4 min	UTrack
9	F	14	Advanced	1	4 min	Combibaan Hengelo
10	F	24	Advanced	2	4 min	UTrack
11	M	23	Advanced	1	4 min	UTrack
12	F	19	Intermediate	2	4 min	UTrack
13	M	21	Advanced	1	3 min	UTrack
14	M	21	Advanced	1	3 min	UTrack
15	F	19	Advanced	2	4 min	UTrack
16[1,2]	F	20	Advanced	2	4 min	Combibaan Hengelo
17	M	59	Advanced	1	3 min	2.3km straight end
18	F	27	Intermediate	2	3 min	2.3 km straight end

As Table 8.2 shows, 5 out of 18 participant were intermediate in inline skating, while the other 13 participants were advanced skaters. 11 participants were female and 7 were male. The average age of the participant is 24 and the median is 22,5.

8.2.1 Knee angle

During each experiment, the participants skated five trials of 3 to 4 minutes in which the knee angle and posture of the back was measured. For most participants, trials of 4 minutes were performed but due to the outside temperature during certain experiments (>28 degrees Celsius) the trials for some participants were reduced to 3 minutes.

The data for the complete session was recorded in one file. An example of the raw data is shown in Figure 8.1. As the figure shows, there is a clear distinction between when a trial starts and stops. When a person is skating, there data shows large peaks while when a person is stationary, the range of the data is much smaller. The data was split into different trials and the peaks for each leg were detected. Figure 8.2a shows the raw data of the first trial for participant 11. Figure 8.2b shows the detected peaks.

With the peak detection algorithm, it is possible to calculate the average angle and number of strides for all participants. This data is shown in Table 8.3. In some cases, the date detection algorithm missed some peaks, this influences the average knee angle. However, considering that there is large number of strides and only a low number of missed peaks, the missed peaks do not have a large influence on the calculated average knee angle.

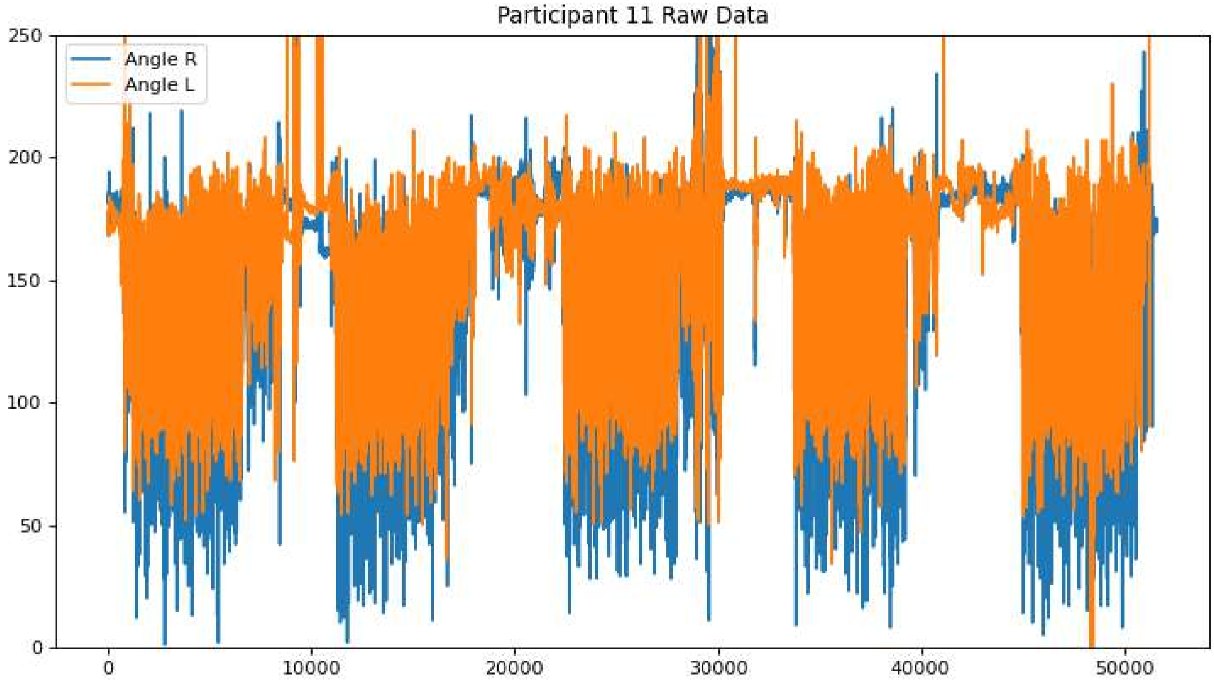
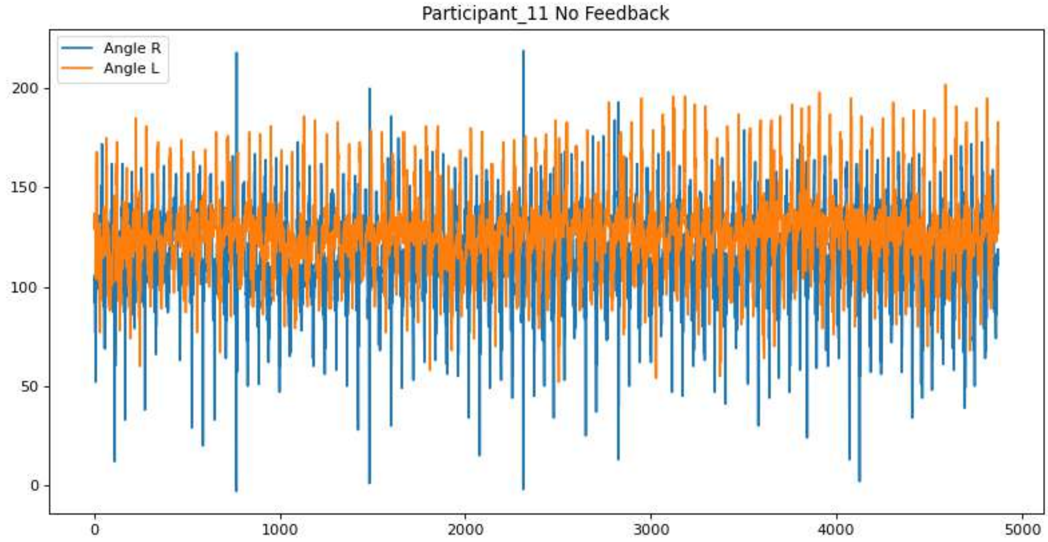
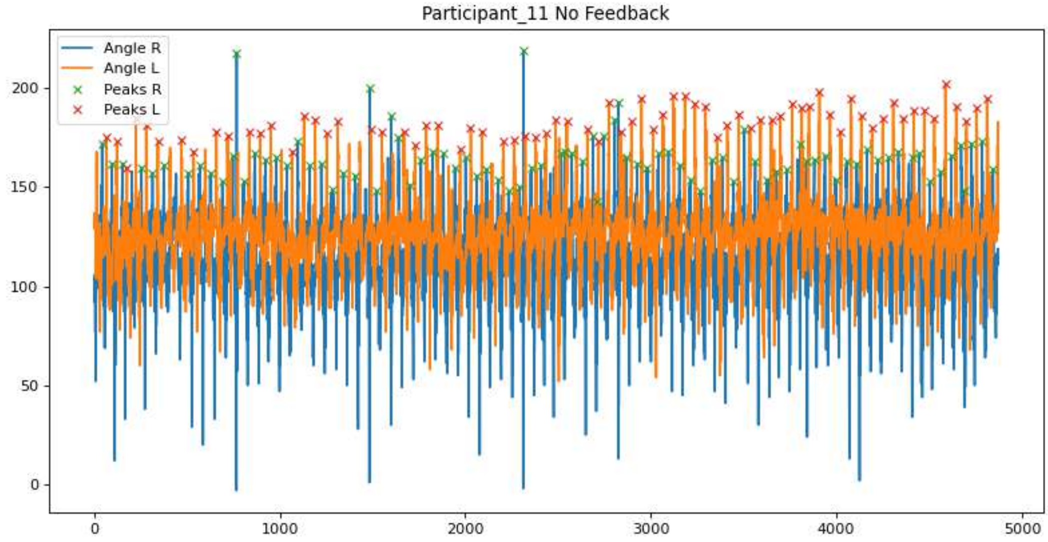


Figure 8.1: The raw data of participant 11. The data consists of 5 trials. The large peaks are part of the trials, the smaller peaks in between indicate that the skater was slowly skating or stationary.



(a) Data of the trial were no feedback was provided.



(b) The peaks in the data.

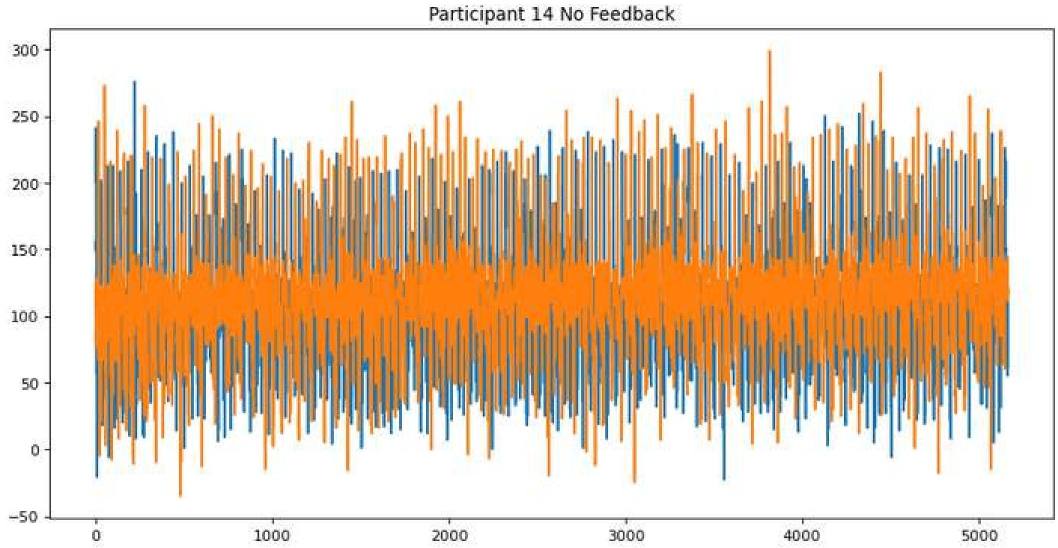
Figure 8.2: Examples of the data after it has been split in different trials and the peaks are detected.

Table 8.3: A table showing the average angle and number of strides during the different trials for each individual participant.

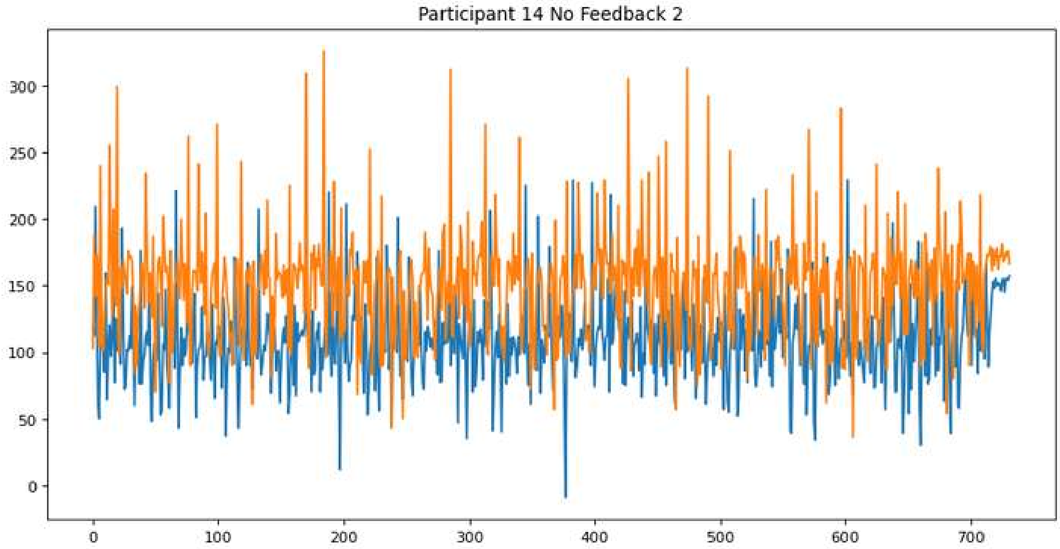
		Average angle					**Number of strides**				
Participant	**Leg**	**No Feedback**	**Knees**	**Back**	**Both**	**No Feedback 2**	**No Feedback**	**Knees**	**Back**	**Both**	**No Feedback 2**
Participant 1	L	132,23	131,95	132,34	131,77	131,75	115	101	98	94	106
Participant 1	R	133,30	132,87	132,48	133,10	133,24	115	101	98	94	106
Participant 2	L	111,59	110,16	116,05	106,65	109,24	120	116	109	118	119
Participant 2	R	109,70	114,20	119,70	119,70	119,67	120	117	110	118	118
Participant 4	L	114,83	119,61	117,30	119,34	123,02	129	101	120	110	96
Participant 4	R	110,71	108,71	107,57	107,66	108,97	128	101	121	109	96
Participant 5	L	121,53	121,84	127,20	124,11	127,47	136	124	117	120	128
Participant 5	R	108,15	109,11	113,44	112,17	114,39	136	124	117	120	128
Participant 6	L	112,19	113,67	113,00	108,20	111,91	157	137	142	141	141
Participant 6	R	98,24	99,58	96,73	97,38	97,98	157	137	142	141	142
Participant 7	L	104,89	106,19	111,01	109,61	111,89	125	123	118	116	129
Participant 7	R	107,39	111,14	120,01	117,14	117,89	125	123	119	116	128
Participant 8	L	119,56	122,25	123,47	126,39	128,05	114	115	115	128	131
Participant 8	R	110,67	113,86	111,23	114,73	116,60	113	115	114	127	132
Participant 9	L	101,79	96,81	99,96	99,81	102,24	114	107	95	109	114
Participant 9	R	104,06	94,47	92,47	93,13	94,55	115	107	95	110	114
Participant 10	L	135,00	133,53	135,06	134,39	135,01	115	101	102	93	98
Participant 10	R	125,21	122,00	126,16	123,43	125,20	115	100	103	94	98
Participant 11	L	131,72	130,07	136,52	134,04	132,95	80	85	82	91	89
Participant 11	R	125,00	126,27	129,83	128,93	128,06	79	85	83	90	90
Participant 12	L	124,06	121,92	126,66	124,02	133,25	105	109	124	109	112
Participant 12	R	119,87	117,55	119,48	117,52	127,00	106	109	124	109	113
Participant 13	L	130,43	129,01	131,37	126,27	128,60	127	136	109	100	117
Participant 13	R	117,67	114,09	113,14	113,96	112,42	127	135	108	99	118
Participant 14	L	118,86	120,35	119,84	118,17	148,82	131	121	74	78	22
Participant 14	R	110,57	111,89	112,62	110,79	108,23	131	122	73	78	21
Participant 15	L	103,00	107,30	107,31	108,31	107,60	149	139	141	142	141
Participant 15	R	107,56	109,44	111,22	111,41	112,42	150	140	142	143	141
Participant 17	L	130,95	124,63	135,98	129,37	135,23	79	76	87	76	80
Participant 17	R	125,94	117,06	119,95	115,81	119,55	78	76	87	76	81
Participant 18	L	129,34	129,97	126,98	135,13	136,51	80	86	76	91	93
Participant 18	R	130,88	130,73	130,71	128,78	128,29	81	87	76	90	94

During four minutes of inline skating, most skaters skated about 4 laps on the 400 m track. The number of strides per lap ranges between 32 and 64. This means that for a 4 minute trial, the strides should range between 128 and 256, which is 64 and 128 strides per leg. Participants 13, 14, 17 and 18 all did trials of 3 minutes instead of 4 minutes. Participant 13 and 14 started off with a 4 minute trial but later for the first two conditions but moved to a 3 minute trial for the last three conditions. For these participants, the number of strides should be between 48 and 96 per leg. The number of strides for each participant and trial are seen in Table 8.3.

Table 8.3 shows that for participant 14, the number of strides was too low (21 and 22 strides) during the last trial. Therefore, the data was inspected. Figure 8.3a shows the data of the first trial of participant 14. During this trial, the sensors worked correctly and the data consists of approximately 5000 data points. During trial 5 (Figure 8.3b) one of the IMUs was not connected properly. This slows the program down, which means that the knee angle is less accurately measured. Therefore, the data of participant 14 is dropped.



(a) Data of the first no feedback trial.



(b) Feedback of the last no feedback trial.

Figure 8.3: Figure comparing the first 'no feedback' trial of participant 14 to the last 'no feedback' trial. During the last trial, the IMUs did not work correctly which influenced the number of measurements and the accuracy of the measurements.

Analysis without fatigue correction

To get an overview of the data, the average knee angle for different conditions is investigated. This is shown in Table 8.4 and Table 8.5.

Table 8.4: The mean values of the knee angle for the left leg, split in different conditions.

Leg = L	**Total**	**Males**	**Females**	**Intermediate**	**Advanced**	**UTrack**	**Combibaan Hengelo**	**Parking Lot**	**Straight end**
No Feedback	120,21	123,61	117,94	125,12	118,42	119,721	101,79	121,91	130,145
Feedback Knees	119,93	123,14	117,79	125,86	117,77	120,539	96,81	121,055	127,3
Feedback Back	122,68	126,90	119,87	125,82	121,54	122,89	99,96	124,195	131,48
Feedback Both	121,16	123,56	119,56	127,57	118,83	121,468	99,81	119,21	132,25
No Feedback 2	123,65	126,53	121,73	131,13	120,93	123,975	102,24	120,495	135,87
N	15	6	9	4	11	10	1	2	2

Table 8.5: The mean values of the knee angle for the right leg, split in different conditions.

Leg = R	**Total**	**Males**	**Females**	**Intermediate**	**Advanced**	**UTrack**	**Combibaan Hengelo**	**Parking Lot**	**Straight end**
No Feedback	115,62	114,29	116,52	123,69	112,69	113,047	104,06	121,5	128,41
Feedback Knees	114,74	112,47	116,25	122,47	111,93	113,175	94,47	123,535	123,895
Feedback Back	116,27	113,44	118,16	122,56	113,99	114,881	92,47	126,09	125,33
Feedback Both	115,66	112,65	117,66	121,77	113,44	114,433	93,13	126,4	122,295
No Feedback 2	117,08	113,56	119,43	124,38	114,43	116,093	94,55	126,455	123,92
N	15	6	9	4	11	10	1	2	2

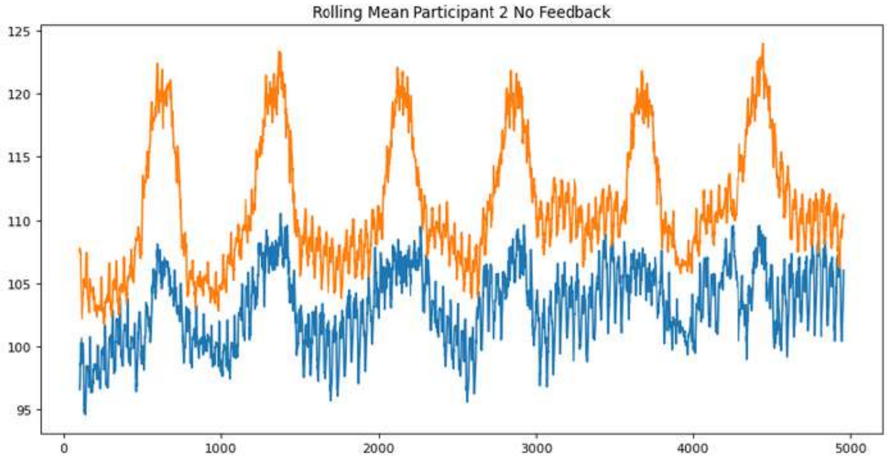
The tables show that the mean angle is higher for the left leg compared to the right leg. The mean of the left leg is around 120 degrees, while the mean of the right leg is around 115. The difference between the left and right leg seems to be larger for advanced inline skater compared to intermediate inline skaters, and more for males compared to females. When comparing locations, the difference between the average knee angle for the left and right leg is largest for the UTrack.

To investigate the difference between the average knee angle of the left and right leg, the moving average of the knee angle is computed. The plots with the moving averages for participant 2, 8 and 17 are shown in Figure 8.4. The graphs show that the mean angle of the participants 2 and 8 periodically move up for the left leg but not for the right leg. The peaks of the left leg are caused by the corners. For participant 2 (Figure 8.4a) the data was recorded on a parking lot which had shorter corners compared to the UTrack, where the data for participant 8 was recorded (Figure 8.4b). The graphs show that the width of the peaks for participant 2 are smaller compared to the with of the peaks for participant 8 for the left leg, which is caused by the fact that the corners are shorter. The trial for participant 17 (Figure 8.4c) was recorded on a straight end. For this participants, there are no peaks as shown in the graphs of participant 2 and 8.

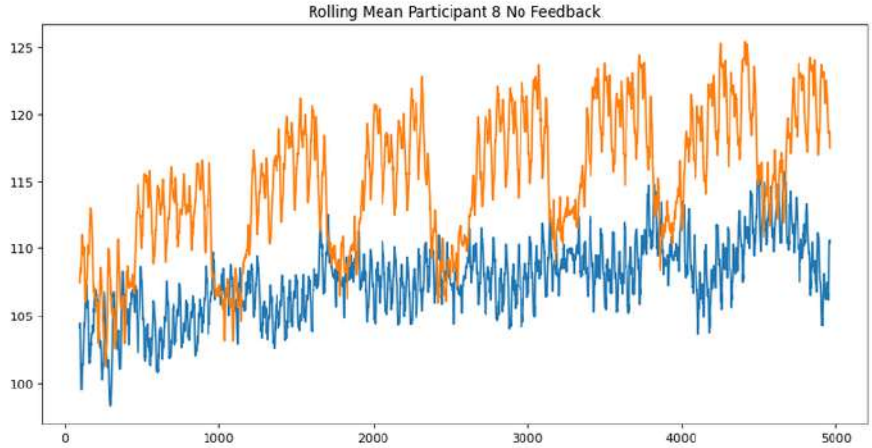
In the corners, a cross over takes place, which takes up more energy from the left leg compared to the right leg, considering that a skater glides mostly on the left leg in the corners. Moreover, the skaters try push the hip towards the corner. This means that the hip, knee and toe are not directly above each other. (see Figure 8.5). This could cause the sensor readings to be altered, considering that the sensor data is influenced if the sensors are not directly above each other. However, this happens during all trials which means that it should not influence the data when comparing the knee angles. This also does not explain why the average knee angle when skating on the parking lot is lower for the right leg compared to the left leg, considering that based on the graphs, the average knee angle for the left leg should be higher.

Moreover, the descriptive statistics show that for the total mean, the average knee angle is lower when feedback is provided to the knee only compared to when no feedback is provided to the knee, which indicates that the vibrotactile feedback could improve posture.

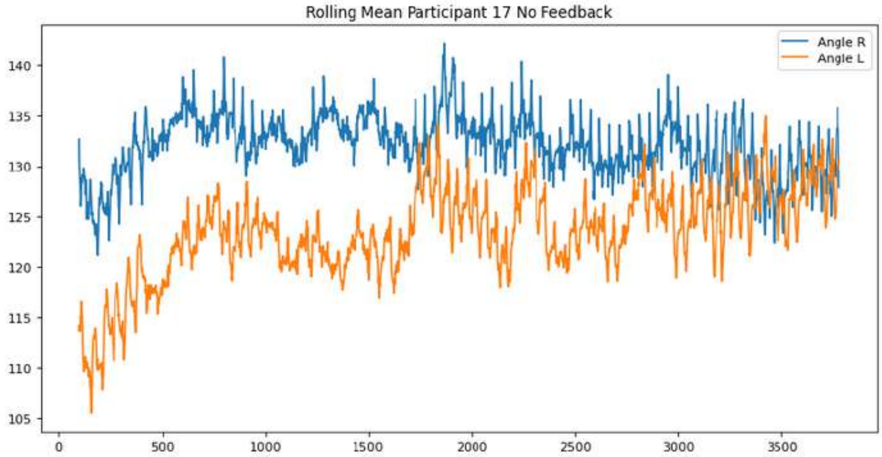
The knee angle when feedback is provided to the back and knee is not lower compared to the no feedback session. This could be caused by fatigue. The data shows that the knee angle is lower for the first no feedback trial compared to the last no feedback trial, which could indicate that participants get tired over the course of the experience. This effect seems larger for females compared to males, and larger for intermediate inline skaters compared to advanced inline skaters. For the participants on Combibaan



(a) A plot showing the moving averages for the first trial of participant 2. The window of the moving average is 100. The trial was performed at a parking lot.



(b) A plot showing the moving averages for the first trial of participant 8. The window of the moving average is 100. The trial was performed on the UTrack



(c) A plot showing the moving averages for the first trial of participant 17. The window of the moving average is 100. The trial was performed on a straight end.

Figure 8.4: Plots showing the moving average of the data for the knee angle. The plots show that for locations with corners, the angle of the left leg periodically moves up due to the corner. The parking lot has sharper corners compared to teh UTrack, which explains why the peaks of (a) are narrower compared to the peaks of (b). (c) does not show the periodical peaks as the data was recorded on a straight end.

Figure 8.5: A professional inline skater going through a corner. The skater pushes his hip inwards and hangs inwards, meaning that the toe-knee-hip line is not perpendicular to the ground.

Hengelo and on the straight end, a lower knee angle is measured during the last trial compared to the first, which could indicate a learning effect.
To determine whether the average knee angle is statistically different between the different trials, a repeated measures ANOVA is performed. A repeated measures ANOVA detects if there is a difference between related means. The null hypothesis for the repeated measures ANOVA is that all means are equal. The alternative hypothesis is that at least two means are significantly different. To see whether a repeated measures ANOVA is suitable to use with the data, the assumptions of the repeated measures ANOVA are checked.

1. **The observations are sampled independently.**
   The observations are sampled independently. All subjects are independent.

2. **The independent variable consists of at least two related groups or matched pairs.**
   The independent variable consist of five related groups, which are the five trials with and without feedback. The test compares conditions in a within-subject study. However, the sensors both output value for the left and right leg. This data is dependent on each other. Therefore, the data is split and each leg is tested separately in the ANOVA.

3. **The distribution of the dependent variable in the groups is approximately normally distributed**
   To see whether the data is normally distributed, a Shapiro-Wilk test is performed. A Shapiro-Wilk Test tests whether data is normally distributed or not. The test has the following hypothesis:

   H_0: The data is normally distributed.
   H_A: The data is not normally distributed.

   This hypothesis is tested for a significant level of 5%, which means that the null hypothesis is rejected if the significance value is below 0.05.

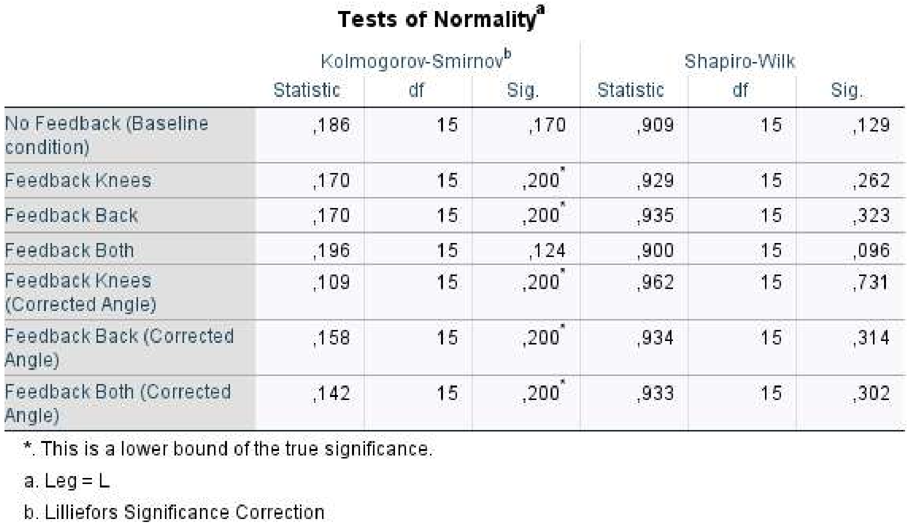
   The result of the Shapiro-Wilk Test is shown in Table 8.6. The test shows that for both the left and the right leg, none of the significance values is below 0.05, which means that the null hypothesis cannot be rejected. This means that the data is normally distributed.

4. **Sphericity: the variances of the difference between all combinations of related groups must be equal.**
   Sphericity is tested when performing the repeated measures ANOVA. Based on the results of sphericity test, different p-values are relevant for the ANOVA Test.

The aim of the ANOVA is to detect whether the average knee angle for the different trials is the same or different. Moreover, the effects of gender, experience and location is also investigated. Considering

Table 8.6: The results of the Shapiro Wilk test to test whether the data is normally distributed.

(a) The Shapiro-Wilk Test for the left leg. The significance value for Shapiro-Wilk is larger than 0.05, which means that the data is normally distributed.



Tests of Normality[a]

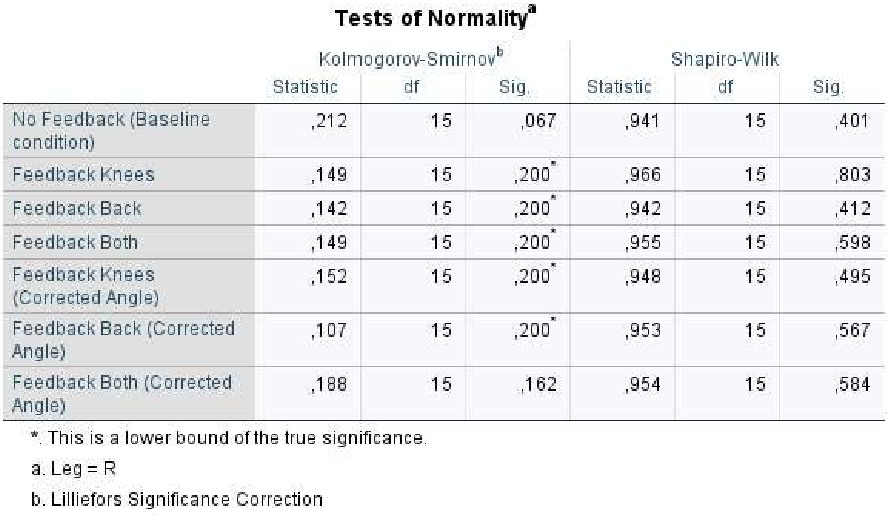
	Kolmogorov-Smirnov[b]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
No Feedback (Baseline condition)	,186	15	,170	,909	15	,129
Feedback Knees	,170	15	,200*	,929	15	,262
Feedback Back	,170	15	,200*	,935	15	,323
Feedback Both	,196	15	,124	,900	15	,096
Feedback Knees (Corrected Angle)	,109	15	,200*	,962	15	,731
Feedback Back (Corrected Angle)	,158	15	,200*	,934	15	,314
Feedback Both (Corrected Angle)	,142	15	,200*	,933	15	,302

*. This is a lower bound of the true significance.

a. Leg = L

b. Lilliefors Significance Correction

(b) The Shapiro-Wilk Test for the right leg. The significance value for Shapiro-Wilk is larger than 0.05, which means that the data is normally distributed.



Tests of Normality[a]

	Kolmogorov-Smirnov[b]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
No Feedback (Baseline condition)	,212	15	,067	,941	15	,401
Feedback Knees	,149	15	,200*	,966	15	,803
Feedback Back	,142	15	,200*	,942	15	,412
Feedback Both	,149	15	,200*	,955	15	,598
Feedback Knees (Corrected Angle)	,152	15	,200*	,948	15	,495
Feedback Back (Corrected Angle)	,107	15	,200*	,953	15	,567
Feedback Both (Corrected Angle)	,188	15	,162	,954	15	,584

*. This is a lower bound of the true significance.

a. Leg = R

b. Lilliefors Significance Correction

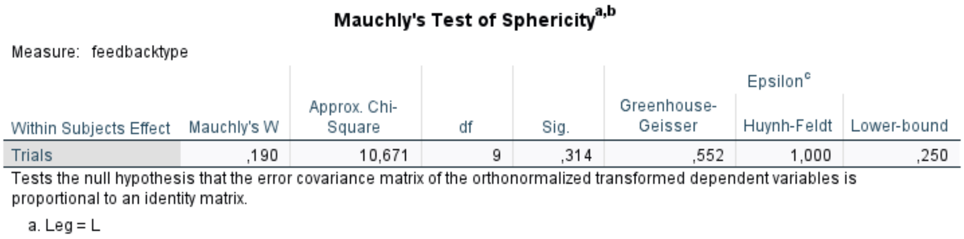
that the sample size for the locations other than the UTrack is very low, it has been decided to group the other locations, to compare the UTrack with locations which are not the UTrack.

First, the sphericity is investigated. These results are shown in Table 8.7. The figures show that for the left leg, the significance value for Mauchley's Test for Sphericity is above 0.05, which means that spericity can be assumed. However, for the right leg, the significance value of Mauchley's Test for Sphericity is <0.001, which means that the sphericity assumption is rejected. Considering that sphericity does not hold, there should be correction for the sphericity. Since Greenhouse-Geisser Epsilon is below 0.75, the Greenhouse-Geisser value is observed.

Table 8.8 shows the results of the repeated measures ANOVA for the left and right leg. The left leg shows the p-values when sphericity is assumed and the right leg shows the data for the Greenhouse-Geisser value. The results of the ANOVA show that for the left leg, the interaction effect between Trials and Experience is statistically significant ($p = 0.013$). However, for the right leg, this interaction effect is not significant ($p = 0.592$). Since there is a significant interaction effect for the left leg, the ANOVA is run

Table 8.7: Results of the tests for Sphericity.

(a) The test for sphericity of the left leg.



Mauchly's Test of Sphericity[a,b]

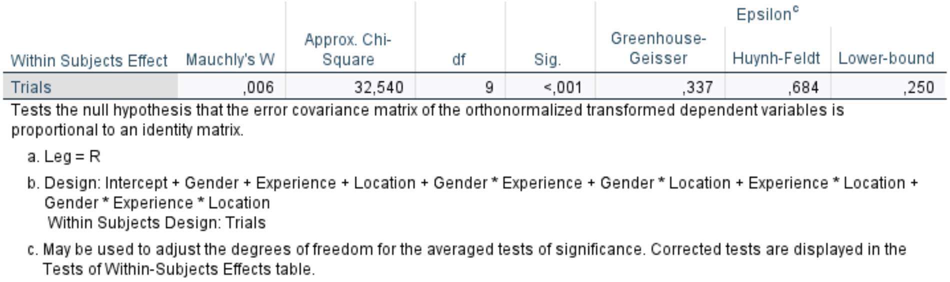
Measure: feedbacktype

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[c] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Trials	,190	10,671	9	,314	,552	1,000	,250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Leg = L

(b) The test for sphericity of the right leg.



Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[c] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Trials	,006	32,540	9	<,001	,337	,684	,250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Leg = R

b. Design: Intercept + Gender + Experience + Location + Gender * Experience + Gender * Location + Experience * Location + Gender * Experience * Location
Within Subjects Design: Trials

c. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

again to analyse the influence of the different trials and of experience.

To investigate which means are different, a pairwise comparison is done between the different trials for the two experience levels. The p-values of the pairwise comparison are adjusted for multiple testing using the False Discovery Rate. Table 8.9 shows the results of the comparison.

Table 8.9 shows that advanced inline skaters improve their knee angle when feedback is provided to the knee only with approximately 0.65 degree. Intermediate inline skaters do not improve their knee angle, considering that the knee angle is higher with approximately 0.75 degrees.

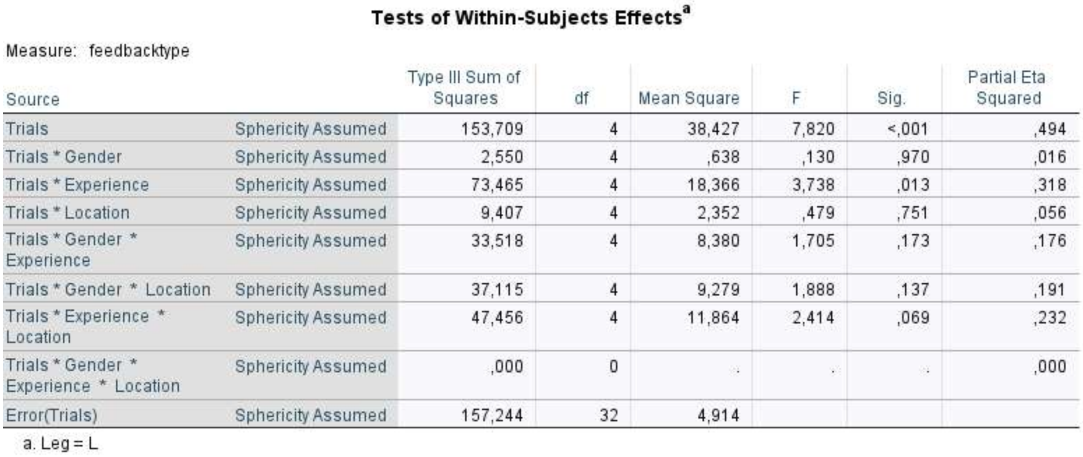
The table also shows that there is a significant difference for advanced skaters between the average knee angle when no feedback is provided and when feedback is provided to the back. The knee angle when feedback is provided to the back is 3.12 degrees higher compared to the baseline trial. The participants were aware when feedback was provided to the back, so it could be that the participants did not try to make a low knee angle during these sessions, which explains why the knee angle is high for the sessions where feedback is provided to the back.

In line with this, there is also a significant difference for advanced inline skaters between the trials were feedback is provided to the back and when feedback is provided to the the back. During the session were feedback is provided to the knee, the knee angle stays low, while during the session were feedback is provided to the back, the knee angle of the inline skaters becomes a lot higher, which causes a statistical significant difference (p=0.02).
For intermediate inline skaters, there is a significant difference between the knee angle when feedback is provided to the back and the second no feedback trial. Based on the above mentioned theory, this is unexpected. It could be that for intermediate inline skaters, the feedback on the back helped to improve the total posture rather than only the knee angle or the curvature of the back.

Table 8.9 also shows that for intermediate inline skaters, there is a significant difference (p=0.04) between the first trial without feedback and last trial without feedback. For intermediate inline skaters, the knee angle is -6.02 degrees lower during the first session compared to the last session. This could indicate that the participants got tired over the course of the experiment. Therefore, the data is corrected for fatigue and analysed again.

Table 8.8: Results of the repeated measures ANOVA.

(a) Results of the ANOVA for the left leg.



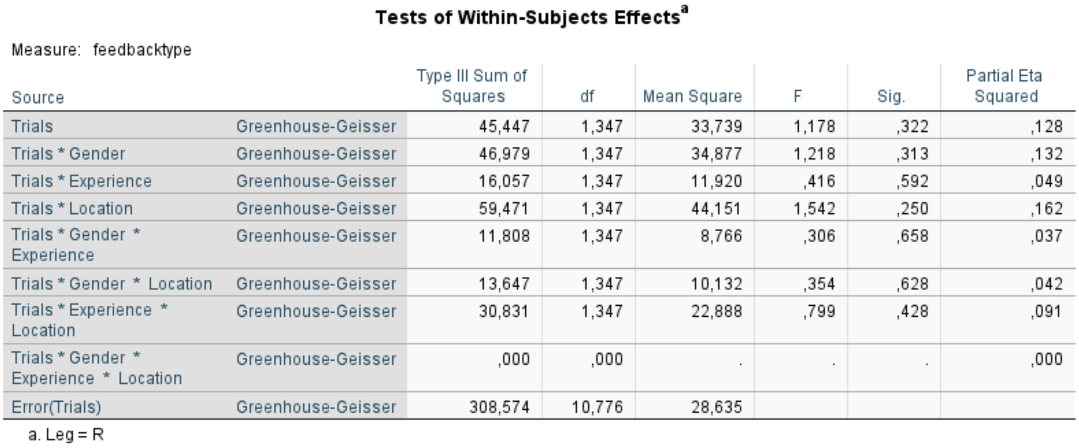
Tests of Within-Subjects Effects[a]

Measure: feedbacktype

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Trials	Sphericity Assumed	153,709	4	38,427	7,820	<,001	,494
Trials * Gender	Sphericity Assumed	2,550	4	,638	,130	,970	,016
Trials * Experience	Sphericity Assumed	73,465	4	18,366	3,738	,013	,318
Trials * Location	Sphericity Assumed	9,407	4	2,352	,479	,751	,056
Trials * Gender * Experience	Sphericity Assumed	33,518	4	8,380	1,705	,173	,176
Trials * Gender * Location	Sphericity Assumed	37,115	4	9,279	1,888	,137	,191
Trials * Experience * Location	Sphericity Assumed	47,456	4	11,864	2,414	,069	,232
Trials * Gender * Experience * Location	Sphericity Assumed	,000	0	.	.	.	,000
Error(Trials)	Sphericity Assumed	157,244	32	4,914			

a. Leg = L

(b) Results of the ANOVA for the right leg.



Tests of Within-Subjects Effects[a]

Measure: feedbacktype

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Trials	Greenhouse-Geisser	45,447	1,347	33,739	1,178	,322	,128
Trials * Gender	Greenhouse-Geisser	46,979	1,347	34,877	1,218	,313	,132
Trials * Experience	Greenhouse-Geisser	16,057	1,347	11,920	,416	,592	,049
Trials * Location	Greenhouse-Geisser	59,471	1,347	44,151	1,542	,250	,162
Trials * Gender * Experience	Greenhouse-Geisser	11,808	1,347	8,766	,306	,658	,037
Trials * Gender * Location	Greenhouse-Geisser	13,647	1,347	10,132	,354	,628	,042
Trials * Experience * Location	Greenhouse-Geisser	30,831	1,347	22,888	,799	,428	,091
Trials * Gender * Experience * Location	Greenhouse-Geisser	,000	,000	.	.	.	,000
Error(Trials)	Greenhouse-Geisser	308,574	10,776	28,635			

a. Leg = R

Table 8.9: A pairwise comparison of the mean knee angle for the left leg. The graph shows the difference in mean values for the different trials and different experience levels. The bold values are statistical significant.

Experience	**I**	**J**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**Adjusted p-value**
Intermediate	No Feedback	Feedback Knees	-0,75	1,55	0,64	0,71
		Feedback Back	-0,71	1,29	0,59	0,71
		Feedback Both	-2,45	1,97	0,24	0,47
		No Feedback 2	-6,02	1,94	0,01	**0,04**
	Feedback Back	No Feedback	0,71	1,29	0,59	0,71
		Feedback Knees	-0,04	1,74	0,98	0,98
		Feedback Both	-1,74	1,93	0,38	0,55
		No Feedback 2	-5,31	1,68	0,01	**0,04**
	No Feedback 2	No Feedback	6,02	1,94	0,01	**0,04**
		Feedback Knees	5,27	2,04	0,02	0,06
		Feedback Back	5,31	1,68	0,01	**0,04**
		Feedback Both	3,57	1,31	0,02	0,06
Advanced	No Feedback	Feedback Knees	0,65	0,93	0,50	0,62
		Feedback Back	-3,12	0,78	0,00	**0,01**
		Feedback Both	-0,41	1,19	0,74	0,74
		No Feedback 2	-2,50	1,17	0,05	0,09
	Feedback Back	No Feedback	3,12	0,78	0,00	**0,01**
		Feedback Knees	3,77	1,05	0,00	**0,02**
		Feedback Both	2,71	1,16	0,04	0,07
		No Feedback 2	0,61	1,01	0,55	0,62
	No Feedback 2	No Feedback	2,50	1,17	0,05	0,09
		Feedback Knees	3,16	1,23	0,02	0,06
		Feedback Back	-0,61	1,01	0,55	0,62
		Feedback Both	2,10	0,79	0,02	0,06

Analysis with fatigue correction

To correct for fatigue, it was assumed that a participant gets linearly more tired over the course of the experiment. The knee angle for both sessions without feedback is known and can be used to compensate for the tiredness. The order in which trials were done was also taken into account. The corrected knee angles can be seen in Table F.1 in Appendix F. The descriptive statistics for the corrected angles are shown in Table 8.10 and Table 8.11.

Table 8.10: The mean values of the knee angle for the left leg, corrected for fatique, split in different conditions.

Leg = L	**Total**	**Males**	**Females**	**Intermediate**	**Advanced**	**UTrack**	**Combibaan Hengelo**	**Parking Lot**	**Straight end**
No Feedback	120,21	123,61	117,94	125,12	118,42	119,72	101,79	121,91	130,15
Feedback Knees	118,56	122,08	116,21	122,82	117,01	118,84	96,70	121,70	124,97
Feedback Back	121,47	125,77	118,60	124,35	120,42	121,40	99,73	124,61	129,52
Feedback Both	118,58	121,36	116,72	123,05	116,95	118,28	99,48	120,27	127,96
N	15	6	9	4	11	10	1	2	2

Table 8.11: The mean values of the knee angle for the right leg, corrected for fatique, split in different conditions.

Leg = R	**Total**	**Males**	**Females**	**Intermediate**	**Advanced**	**UTrack**	**Combibaan Hengelo**	**Parking Lot**	**Straight end**
No Feedback	115,62	114,29	116,52	123,69	112,69	113,05	104,06	121,50	128,41
Feedback Knees	114,07	112,73	114,96	122,12	111,14	112,14	96,84	121,06	125,35
Feedback Back	115,85	113,72	117,27	122,40	113,47	113,63	97,23	124,86	127,25
Feedback Both	114,56	113,20	115,47	121,25	112,13	112,15	100,26	122,69	125,67
N	15	6	9	4	11	10	1	2	2

When comparing the corrected descriptive statistics to the uncorrected descriptive statistics (see Table 8.4 and Table 8.5) it can be seen that the corrected knee angle is lower compared to the uncorrected knee angle, which is as expected considering that inline skaters usually make a larger knee angle when they are getting tired.

The descriptive statistics show that the knee angle lowers when feedback is provided to the knee. For intermediate inline skaters, the difference between the knee angle for the no feedback sessions and when feedback is provided to the knee is larger compared to advanced inline skaters. Moreover, the data shows that for the sessions 'feedback knees' and 'feedback both' the average knee angle is similar. The difference between the two sessions is approximately 0.5 degrees for all genders and experience levels.

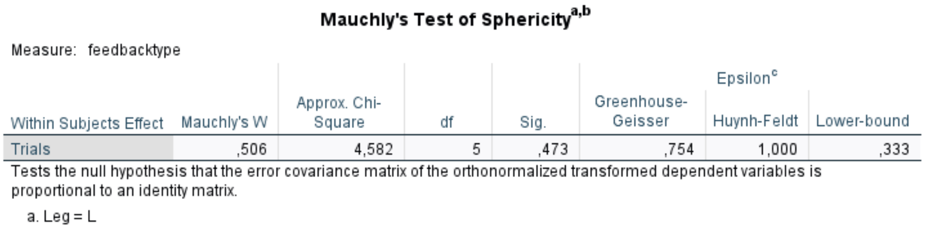
To detect whether the differences between the different trials are significant, the repeated measures ANOVA is done for the data corrected for fatigue. First, the test for sphericity is done to see whether the assumption of sphericity is met. The results of the sphericity test is shown in Table 8.12. The sphericity test show that for both the left and right leg, the significance value for Mauchley's Test for sphericity is above 0.05. This means that sphericity can be assumed. Therefore, the ANOVA is performed.

Table 8.13 shows the results of the ANOVA test. The test shows that for the right leg, none of the test are significant which means that for the right leg, there is no significant difference between the mean knee angle for the participants.

For the left leg, there is a significant interaction effect between trials, experience and location, and between trials, experience and gender. These interaction effects are further evaluated. Considering the small sample size (N=15) it was decided to look at the descriptive statistics rather than performing post-hoc tests. When performing post-hoc tests taking two factors into account, the sample size per group becomes very small which makes the power of the statistical test low.

Table 8.12: Results of the tests for sphericity for the data that is corrected for fatigue.

(a) The test for sphericity of the left leg.



Mauchly's Test of Sphericity[a,b]

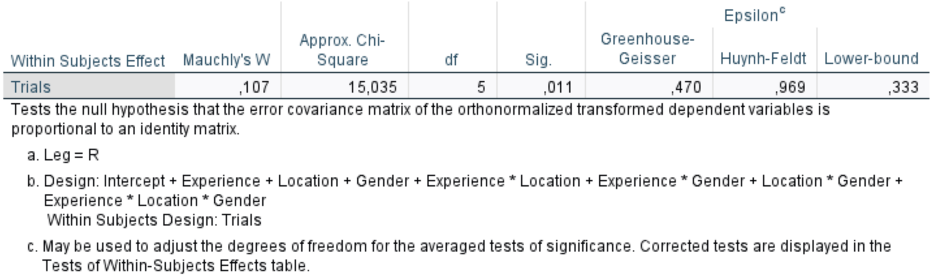
Measure: feedbacktype

					Epsilon[c]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Trials	,506	4,582	5	,473	,754	1,000	,333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Leg = L

(b) The test for sphericity of the right leg.



					Epsilon[c]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Trials	,107	15,035	5	,011	,470	,969	,333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

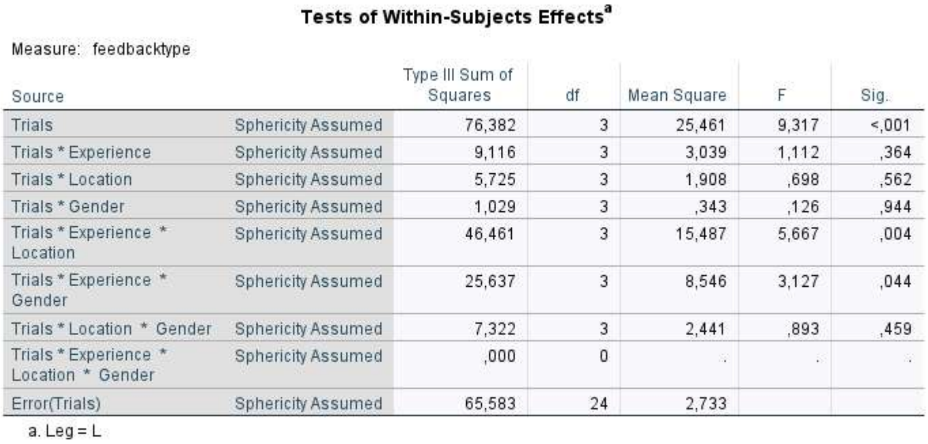
a. Leg = R

b. Design: Intercept + Experience + Location + Gender + Experience * Location + Experience * Gender + Location * Gender + Experience * Location * Gender
Within Subjects Design: Trials

c. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 8.13: Results of the repeated measures ANOVA for the data which is corrected for fatigue.

(a) Results of the ANOVA for the left leg.



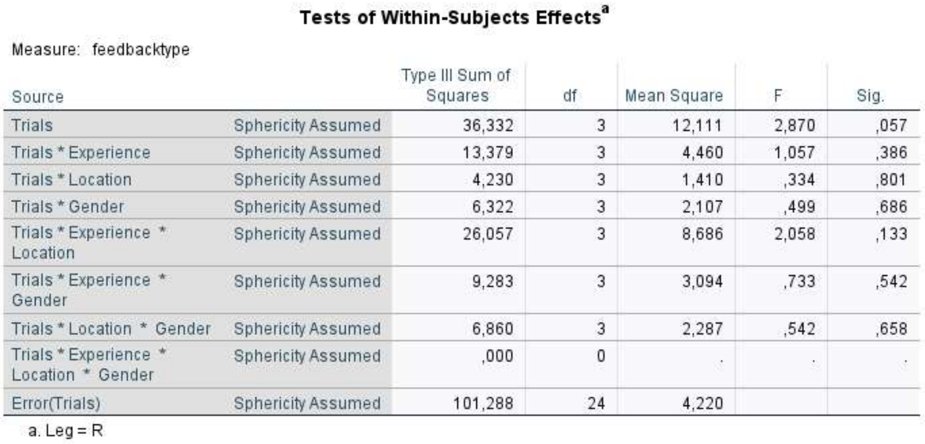
Tests of Within-Subjects Effects[a]

Measure: feedbacktype

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Trials	Sphericity Assumed	76,382	3	25,461	9,317	<,001
Trials * Experience	Sphericity Assumed	9,116	3	3,039	1,112	,364
Trials * Location	Sphericity Assumed	5,725	3	1,908	,698	,562
Trials * Gender	Sphericity Assumed	1,029	3	,343	,126	,944
Trials * Experience * Location	Sphericity Assumed	46,461	3	15,487	5,667	,004
Trials * Experience * Gender	Sphericity Assumed	25,637	3	8,546	3,127	,044
Trials * Location * Gender	Sphericity Assumed	7,322	3	2,441	,893	,459
Trials * Experience * Location * Gender	Sphericity Assumed	,000	0	.	.	.
Error(Trials)	Sphericity Assumed	65,583	24	2,733		

a. Leg = L

(b) Results of the ANOVA for the right leg.



Tests of Within-Subjects Effects[a]

Measure: feedbacktype

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Trials	Sphericity Assumed	36,332	3	12,111	2,870	,057
Trials * Experience	Sphericity Assumed	13,379	3	4,460	1,057	,386
Trials * Location	Sphericity Assumed	4,230	3	1,410	,334	,801
Trials * Gender	Sphericity Assumed	6,322	3	2,107	,499	,686
Trials * Experience * Location	Sphericity Assumed	26,057	3	8,686	2,058	,133
Trials * Experience * Gender	Sphericity Assumed	9,283	3	3,094	,733	,542
Trials * Location * Gender	Sphericity Assumed	6,860	3	2,287	,542	,658
Trials * Experience * Location * Gender	Sphericity Assumed	,000	0	.	.	.
Error(Trials)	Sphericity Assumed	101,288	24	4,220		

a. Leg = R

Table 8.14: The descriptive statistics of the interaction effect of Trials*Experience*Gender

Gender	**Experience**	**Trial**	**Mean**	**Std. Error**	**95% Confidence Interval** **Lower Bound**	 **Upper Bound**	**N**
Male	Intermediate	No Feedback	114,83	10,98	89,51	140,15	1
		Feedback Knees	115,51	10,26	91,85	139,18	1
		Feedback Back	115,26	11,49	88,77	141,75	1
		Feedback Both	113,20	11,19	87,40	139,00	1
	Advanced	No Feedback	127,46	6,14	113,31	141,61	5
		Feedback Knees	123,45	5,74	110,22	136,68	5
		Feedback Back	130,11	6,42	115,30	144,92	5
		Feedback Both	124,18	6,26	109,76	138,61	5
Female	Intermediate	No Feedback	127,42	6,72	111,92	142,93	3
		Feedback Knees	123,28	6,28	108,79	137,77	3
		Feedback Back	126,62	7,04	110,40	142,85	3
		Feedback Both	124,03	6,85	108,23	139,83	3
	Advanced	No Feedback	111,15	4,75	100,19	122,11	6
		Feedback Knees	109,77	4,44	99,53	120,02	6
		Feedback Back	112,71	4,97	101,23	124,18	6
		Feedback Both	109,93	4,85	98,75	121,10	6

Table 8.14 shows the descriptive statistics for the interaction effect of gender, experience and trials. The table shows that for the advanced males and all females, the knee angle is lower for conditions where feedback is provided to the knee compared to when no feedback is provided based on the knee angle. For the three categories, the average knee angles in session 'Feedback Knees' and 'Feedback Both' is lower compared to the knee angle is sessions 'No Feedback' and 'Feedback Both'. This indicates that the knee angle of skaters gets lower when feedback is provided to the knee.

For the intermediate male, the knee angle is not lower during the session where feedback is provided only to the knee compared to the no feedback session. However, the knee angle is lower when feedback is provided to both the back and the knee. This is the data of 1 participants, which makes it not possible to draw conclusions based on these findings.

For the intermediate females, the knee angle is lower when feedback is provided to the back compared to the 'no feedback' trial. However, the knee angle is higher compared to the situation where feedback is provided to the knee. This could indicate that a learning effect took place between the 'no feedback' session and the session where feedback was provided to the back.

For the other groups, the knee angle during the trials where feedback is provided to the back is higher compared to the no feedback trial.

Next, the descriptive statistics of the interaction effect between trials, experience and location are investigated. These descriptive statistics are shown in Table 8.15. The descriptive statistics show that intermediate and advanced inline skaters on the UTrack have a lower knee angle when feedback is provided to the knees compared to when feedback is not provided. However, the difference between the knee angle when no feedback is provided and when feedback is provided is larger for intermediate skaters compared to advanced skaters on the UTrack.

One explanation for this could be that not all intermediate skaters do a cross over in the corners, while the advanced skaters do a cross over. The corners on the UTrack are very wide, which makes it difficult do cross over steps only. This could have influenced the skating technique of the advanced skaters. This could also explain why there is larger improvement in knee angle for the advanced skaters which were not on the UTrack when feedback is provided to the knee. On the parking lot, the corners were sharper which allowed the inline skaters to do cross over steps. The straight end did not have corners, which means that the participants were not influenced by the inability to do proper cross overs.

Table 8.15: The descriptive statistics of the interaction effect of Trials*Experience*Location

Experience			**Mean**	**Std. Error**	**95% Confidence Interval**		
					Lower Bound	**Upper Bound**	**N**
Intermediate	UTrack	No Feedback	119,45	7,76	101,54	137,35	2
		Feedback Knees	116,42	7,26	99,69	133,15	2
		Feedback Back	119,81	8,12	101,08	138,54	2
		Feedback Both	115,17	7,91	96,92	133,41	2
	Not UTrack	No Feedback	130,79	7,76	112,88	148,69	2
		Feedback Knees	129,23	7,26	112,49	145,96	2
		Feedback Back	128,89	8,12	110,15	147,62	2
		Feedback Both	130,94	7,91	112,69	149,18	2
Advanced	UTrack	No Feedback	119,79	3,88	110,84	128,74	8
		Feedback Knees	119,44	3,63	111,07	127,81	8
		Feedback Back	121,80	4,06	112,43	131,17	8
		Feedback Both	119,06	3,96	109,93	128,18	8
	Not UTrack	No Feedback	118,82	6,72	103,32	134,32	3
		Feedback Knees	113,79	6,28	99,30	128,28	3
		Feedback Back	121,01	7,04	104,79	137,24	3
		Feedback Both	115,05	6,85	99,25	130,85	3

Conclusion

This section analysed the knee angle during the different trials. The descriptive statistics shows that there is a difference in the mean knee angle between the left and right leg. It is suspected that this difference comes from the cross overs which are performed in the corners during inline skating.

The results of the repeated measures ANOVA shows that there is an interaction effect between the trials and the experience of the inline skater for the left leg. For the right leg, this interaction effect was not found.

The post-hoc tests showed that there is a significant difference for intermediate skaters between the first and last no feedback trial. The average angle is 6.02 degrees higher during the last trial compared to the first which indicates that the skaters get tired over the course of the experiment. Moreover, the intermediate participants had the lowest knee angle when feedback was provided to the back, which could indicate that feedback to the back also helped the inline skaters to improve their knee angle.

For advanced inline skaters, The knee angle is 3.77 degrees lower when feedback is provided to the back compared to the knee. This indicates that participants lower their knee angle when feedback is provided to their knees and higher their angle when they are aware that the knee angle is not of importance during the session.

When the data is corrected for fatigue, the descriptive statistics show that the average knee angle is lower when feedback is provided to the knee compared to when no feedback is provided. This is the case for both genders and both experience levels. The average reduction in knee angle is -1.64 degrees for the right leg and -1.305 degrees for the right leg.

The repeated measures ANOVA shows two interaction effects. The first interaction effect is between trials, experience and location and the second interaction effect is between trials, experience and gender.

The interaction effect between trials, experience and location show that intermediate inline skaters on the UTrack have a larger improvement in knee angle compared to advanced inline skater. This could be caused by the wide corners of the UTrack which makes it difficult to do proper cross over steps. For advanced skaters on other locations, there is a much larger improvement in knee angle which could be explained by the fact that these skaters were not influenced by the wide corners.

Overall, the data shows that the average knee angle of participants in different situations gets lower when feedback is provided to the knee angle compared to when feedback is not provided to the knee angle, which means that the wearable is effective to coach inline skaters to make a lower knee angle.

8.2.2 Curvature back

Next, the results of the measurements of the posture of the back are investigated. During the calibration procedure, the minimum and maximum delta for the posture of the back was determined. Based on these values, the participants received feedback on their posture. The calibrated minimum and maximum value are also used to determine for how many percent of the trial the user had a correct posture. This percentage is compared between trials to see whether the participants has a better posture when feedback is provided compared to when feedback is not provided. The data is shown in Table 8.16. The table shows that for experiments with some participants, the algorithm measured that the curvature of the back was correct for less than 10 percent of the trial. This is unlikely, considering that all skaters are intermediate to advanced skaters who are aware of their posture. Therefore, it was decided to delete the trials of participants where the data is clearly incorrect. This is the case for participants 3, 9, 14 and 18.

Table 8.16: The percentage of measurements that a participant had the correct posture for the back during the different trials.

Participants	**No Feedback**	**Knees**	**Back**	**Both**	**No Feedback 2**
1	66,40	67,28	63,17	64,64	69,40
2	18,97	6,27	9,70	16,57	20,82
3	11,42	3,18	3,79	6,60	1,41
4	29,18	26,43	38,65	28,56	44,68
5	47,97	51,12	51,98	54,64	50,06
6	20,60	20,40	20,97	37,17	34,08
7	35,84	25,03	32,32	23,44	25,61
8	43,98	45,82	49,60	50,86	45,38
9	3,91	1,06	1,80	0,33	1,54
10	30,57	25,56	24,44	14,76	18,92
11	11,68	4,87	25,88	38,30	32,77
12	34,56	55,13	56,13	52,47	31,08
13	21,89	21,01	19,27	22,96	26,13
14	10,54	1,27	0,56	0,48	0,41
15	21,96	35,80	20,99	32,13	5,20
17	56,54	50,05	24,70	24,62	20,74
18	7,53	12,37	4,42	5,72	3,35

The descriptive statistics of the curvature of the back for different categories are shown in Table 8.17. The descriptive statistics show that the participant have their posture correct for approximately 33 percent of the trial. The means show that females have a correct posture for a longer period of time compared to males and that intermediate inline skaters score better than advanced inline skaters. This is unexpected, considering that it is expected that advanced inline skaters are more aware of their posture and have a better posture compared to intermediate inline skaters.

The table also shows that the percentage of time which the posture was correct increases for intermediate inline skaters over the trials. When feedback is provided to the back, the intermediate inline skaters maintain the correct posture for the longest, which is as expected. However, for advanced inline skaters, the posture of the back does not improve when feedback is provided to the back.

The data also shows that for inline skaters on the UTrack, the posture improves when feedback is provided to the back. For both participants on the parking lot and straight end, the posture does not improve when feedback is provided to the back.

To test whether the posture is better when feedback is provided compared to when feedback is not provided, a Paired Sign Test is done. The Paired Sign Test was chosen instead of the repeated measures ANOVA considering that the data contains outliers. Outliers influence the results of the repeated measures ANOVA, but do not influence a paired sign test. Moreover, the data is not symmetrical for all trials, which makes the Wilcoxon Signed Rank Test unsuitable.

Table 8.17: The descriptive statistics of the correct posture for different factors.

	Total	**Males**	**Females**	**Intermediate**	**Advanced**	**UTrack**	**Parking Lot**	**Straight end**
No Feedback	33,86	31,31	36,04	43,38	31,00	29,82	42,69	56,54
Feedback Knees	33,44	28,98	37,27	49,61	28,59	31,12	36,78	50,05
Feedback Back	33,68	30,24	36,62	52,65	27,99	34,02	36,44	24,70
Feedback Both	35,47	34,38	36,41	48,56	31,55	35,53	40,61	24,62
No Feedback 2	32,68	34,74	30,92	48,39	27,97	31,39	45,11	20,74
N	13	6	7	3	10	10	1	2

Paired Sign Test

First, the assumptions for the paired sign test should be checked, so that the data meets all assumptions. The paired sign test is only performed for the complete data test, considering that the sample size is too small to do a paired sign test for the different groups. Instead, the number of positive and negative ranks are written down for the separate groups.

1. **The dependent variable should be measured at the ordinal or continuous level.**
   The dependent variable is percentages, which can be regarded as a continuous variable in statistics.
2. **The independent variable should consist of two categorical "related groups" or "matched pairs".**
   The independent variable consists of two groups because it compares the two different feedback conditions.
3. **The paired observations should be independent.**
   The data of one participant does not influence the data of other participants, which means that the the paired observations are independent.

The aim of the paired sign test is to answer the following questions:

1. Does the posture of the back improve when feedback is provided to the posture of back?
2. Is there a difference in posture of the back when feedback is provided only to the back compared to when it is provided to both the knee angle and the back?
3. How does posture of the back change when feedback is provided only to the knee angle?
4. How does fatigue influence the data?

To answer the above mentioned questions, 5 null hypotheses and alternative hypotheses are written down which are used to tested for the Paired Sign Test. Hypothesis 1 is done to answer question 1, hypothesis 2 for question 2 and so on. All hypothesis are tested to a significance value of 0.05.

Hypothesis 1.1:

H1.1$_0$: The median of the population difference between the trials with feedback on the posture of the back and trials without feedback is equal to zero.

H1.1$_A$: The median of the population difference between the trials with feedback on the posture the back and trials without feedback is not equal to zero.

Hypothesis 1.2:

H1.2$_0$: The median of the population difference between the trials with feedback on the back and knees and trials without feedback is equal to zero.

H1.2$_A$: The median of the population difference between the trials with feedback on the back and knees and trials without feedback is not equal to zero.

Hypothesis 2:

H2$_0$: The median of the population difference between the trials were feedback is provided solely on the posture of the back and for both the posture of the back and knee angle is equal to zero.

H2$_A$: The median of the population difference between the trials were feedback is provided solely on the posture of the back and for both the posture of the back and knee angle is not equal to zero.

Hypothesis 3:

H3$_0$: The median of the population difference between trials when feedback is provided to the knee angle and the trial without feedback is equal to zero.

H3$_A$: The median of the population difference between trials when feedback is provided to the knee angle and the trial without feedback is not equal to zero.

Hypothesis 4:

H4$_0$: The median of the population difference between the two trials without feedback is equal to zero.

H4$_A$: The median of the population difference between the two trials without feedback is not equal to zero.

Hypothesis 1 First, the conditions in which feedback is provided to the curvature of the back is compared to the baseline condition. The results of these tests are shown in Table 8.18. The test shows that approximately half of the participants perform better when feedback is provided to the back and half of the participant worse. Based on these results, it seems that the wearable does not improve the posture of back of the users. When comparing females and males, it seems that the most males perform better (4 out of 6) when feedback is provided to the back, while most females do not perform better when feedback is provided (2 out of 7 and 3 out of 7). The difference between the negative and positive ranks for the intermediate and advanced skaters is also low. Therefore, the data does not show that the wearable improves posture.

Table 8.18: The results of the Paired Sign Test for hypothesis 1.

Feedback Back - No Feedback			**p-value**
Total	Negative Ranks	7	1,000
	Positive Ranks	6	
	Total	13	
Male	Negative Ranks	2	
	Positive Ranks	4	
	Total	6	
Female	Negative Ranks	5	
	Positive Ranks	2	
	Total	7	
Intermediate	Negative Ranks	1	
	Positive Ranks	2	
	Total	3	
Advanced	Negative Ranks	6	
	Positive Ranks	4	
	Total	10	
Utrack	Negative Ranks	3	
	Positive Ranks	0	
	Total	3	
Not Utrack	Negative Ranks	4	
	Positive Ranks	6	
	Total	10	

Feedback Both - No Feedback			**p-value**
Total	Negative Ranks	6	1,000
	Positive Ranks	7	
	Total	13	
Male	Negative Ranks	2	
	Positive Ranks	4	
	Total	6	
Female	Negative Ranks	4	
	Positive Ranks	3	
	Total	7	
Intermediate	Negative Ranks	2	
	Positive Ranks	1	
	Total	3	
Advanced	Negative Ranks	4	
	Positive Ranks	6	
	Total	10	
Utrack	Negative Ranks	3	
	Positive Ranks	0	
	Total	3	
Not Utrack	Negative Ranks	3	
	Positive Ranks	6	
	Total	10	

It is unexpected that the participants perform worse when feedback is provided on their posture compared to when no feedback is provided to the posture. To investigate why the posture does not improve when feedback is provided, the number of times that feedback was given per person per condition was investigated. This is shown in Table 8.19.

The table shows that the device provided only positive feedback during the trial focused on the posture of the back for all participants except participant 2 and 15. However, the device measured for most participants that the posture was incorrect, so negative feedback should be provided. After inspection of the device and the software, it seems that this is a software mistake. The software checks with a variable

Table 8.19: The number of times that participant received feedback on the back during the trials where feedback was provided to the back.

	Back		**Both**		
Participant	Negative	Positive	Negative	Positive Back	Positive Back and Knees
1	0	0	0	0	0
2	1	7	3	3	3
4	0	8	3	3	3
5	0	7	0	0	0
6	0	8	0	0	1
7	0	7	0	0	0
8	0	7	0	0	1
10	0	8	1	1	2
11	0	7	3	3	0
12	0	8	2	2	2
13	0	6	1	1	1
15	1	8	3	1	3
17	0	6	2	2	2

whether the posture is incorrect or not. If more than 40 measurements out of 60 are incorrect, the posture is declared as incorrect. However, if the variable has not checked more than 40 measurements, the variable reports that the posture is correct instead of reporting that there is no data. This means that participants did receive positive feedback while their posture was not correct. This did not encourage participants to adapt their posture when their posture was wrong since the device indicated that the posture was correct.

Hypothesis 2 Table 8.19 shows the number of times that feedback is given to the back. The table shows that more negative feedback is provided during the trials were feedback was provided both on the posture of the back and the knee angle compared to when feedback was only provided to the back. Therefore, it is expected that the posture is better during the trial where more feedback is provided. This is investigated with the Paired Sign Test shown in Table 8.20. A positive rank indicates that the posture was better when feedback was provided to both parameters rather than only at the back. A negative rank indicates that the posture was better when feedback was provided only at the back and not also at the knee angles.

The results show that for 8 out of 13 participants, the posture is better during the trial were feedback was provided to both the back and the knees compared to when feedback was only provided to the back. For advanced inline skaters, there is a positive change for 7 out of 10 participants. It is expected that users perform better during the session when feedback is provided to the knee and back as the feedback in this session was more accurate compared to the session where feedback is only provided to the back due to a malfunctioning of the device. However, the improvement of the posture is not significant.

Hypothesis 3 Hypothesis 3 compares the data for the baseline condition to the data for when feedback was provided only at the knee angle. It is expected that when users know that there is no feedback, that the posture is worse then when the users know that it their posture is measured. The results of the test (Table 8.21) show that this is indeed the case. The posture of most participants is worse during the trial where feedback is provided only to the knees compared to the baseline trial. Almost all males performed better during the 'No feedback' session compared to when feedback was provided to the the knees. For females, 4 out of 7 participants performed better when feedback was provided to the knees.
For intermediate inline skaters, the analysis on the knee angle showed that their knee angle improved when feedback was provided to the back. The paired sign test shows that for 2 participants the curvature of the back was better when feedback was provided to the knees compared to the no feedback signal. This could indicate that any kind of feedback helps the users to pay attention on their posture and improves both the knee angle and back. However, the sample size is very small so this should be further investigated.

Table 8.20: The results of the Paired Sign Test for hypothesis 2.

Feedback Both - Feedback Back			**p-value**
Total	Negative Ranks	5	0,581
	Positive Ranks	8	
	Total	13	
Male	Negative Ranks	2	
	Positive Ranks	4	
	Total	6	
Female	Negative Ranks	3	
	Positive Ranks	4	
	Total	7	
Intermediate	Negative Ranks	2	
	Positive Ranks	1	
	Total	3	
Advanced	Negative Ranks	3	
	Positive Ranks	7	
	Total	10	
UTrack	Negative Ranks	4	
	Positive Ranks	6	
	Total	10	
Not UTrack	Negative Ranks	1	
	Positive Ranks	2	
	Total	3	

Table 8.21: The results of the Paired Sign Test for hypothesis 3.

Feedback Knees - No Feedback			**p-value**
Total	Negative Ranks	8	0,581
	Positive Ranks	5	
	Total	13	
Male	Negative Ranks	5	
	Positive Ranks	1	
	Total	6	
Female	Negative Ranks	3	
	Positive Ranks	4	
	Total	7	
Intermediate	Negative Ranks	1	
	Positive Ranks	2	
	Total	3	
Advanced	Negative Ranks	7	
	Positive Ranks	3	
	Total	10	
UTrack	Negative Ranks	4	
	Positive Ranks	6	
	Total	10	
Not UTrack	Negative Ranks	2	
	Positive Ranks	1	
	Total	3	

Hypothesis 4 Hypothesis 4 aims to test whether fatigue had an influence on the results of the curvature of the back during the experiments. This is investigated by comparing the first trial without feedback to the last trial without feedback. The results of the Paired Sign Test are shown in Table 8.22. It is expected that the users get tired over time and that the participants perform better during the first trial compared to the last.

The test shows that 8 participants of the 13 performed better in the last trial compared to the first trial. The test also shows that most males perform better for the last trial, while most females perform worse (4 out of 7). For both experience levels, more than half participants performed better during the first trial compared to the last trial. However, there are no large difference meaning that it cannot be concluded that learning or fatigue has an influence on the data.

For the knee angle, fatigue was of influence while it is not for the curvature of the back. This can be explained by the fact that maintaining a low knee angle costs a lot of power, while maintaining the correct curvature costs less power.

Table 8.22: The results of the Paired Sign Test for hypothesis 4.

No Feedback 2 - No Feedback			**p-value**
Total	Negative Ranks	5	0,581
	Positive Ranks	8	
	Total	13	
Male	Negative Ranks	1	
	Positive Ranks	5	
	Total	6	
Female	Negative Ranks	4	
	Positive Ranks	3	
	Total	7	
Intermediate	Negative Ranks	1	
	Positive Ranks	2	
	Total	3	
Advanced	Negative Ranks	4	
	Positive Ranks	6	
	Total	10	
Utrack	Negative Ranks	4	
	Positive Ranks	6	
	Total	10	
Not Utrack	Negative Ranks	1	
	Positive Ranks	2	
	Total	3	

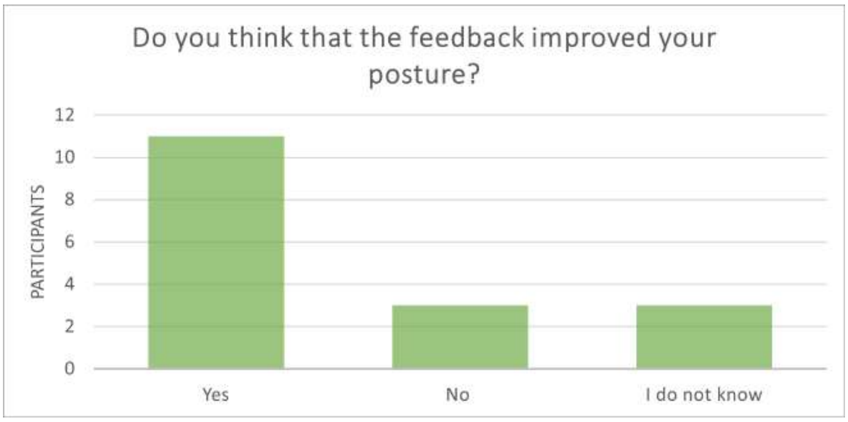
Conclusion

The results on the curvature of the back show that there is no significant improvement when participants receive feedback on their posture compared to when participants do not receive feedback on their posture. Therefore, it can be concluded that the designed wearable does not improve the posture of the curvature of the back for participants.

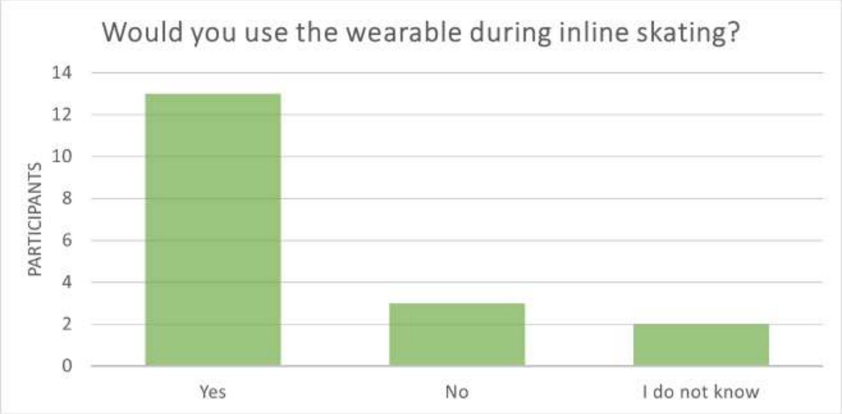
8.2.3 Interviews

After the experiment, a short interview was held with the participants. The interviews are transcribed (see Appendix G). The results of the interviews are discussed in this section.

First of all, the closed questions are discussed. The results of the closed questions are shown in Figure 8.6. As Figure 8.6a shows, 11 out of the 17 participants (1 participant did not answer the question) believed that the feedback improved their posture. The participants mentioned that the vibrations reminded the user to stay in the correct skating posture when they were getting tired. One participant mentioned that she experienced the device as a game, where she tried to beat the device by only getting positive feedback by staying in the correct skating posture. Two participants mentioned that the knee angle was not specifically lower, but that the knee angle was more consist over the four minutes than it would be without feedback. During inline skating, people tend to make a larger knee angle over the course of the 4 minutes due to tiredness. With feedback, this effect was reduced according to these two participants.



(a) The answers to the question: "Do you think that the feedback improved your posture?".



(b) The answers to the question: "Would you use the wearable during inline skating?".

Figure 8.6: Bar graphs showing the opinions of the participants on the wearable.

There are also three participants who did not think their posture improved with the feedback. Participant 4 mentioned that the person was specifically focusing on keeping the sensors happy, rather than making a better posture. The sensors only investigates the knee angle, but not the angle related to the ground, meaning that when pushing the knees forward or backwards the sensors sense that the posture is correct, while the posture is not correct. Participant 5 mentioned that when inline skating, a knee angle is chosen which skates comfortable for a period of 4 laps, rather than the angle that the device wants. The participant did not think that the device was useful for 4 laps, but for longer trials, the participant thought that the device can be useful as with longer trials the users get more tired. The third participant mentioned that his legs were too tired to respond effectively to the feedback of the device, so the feedback did not improve his posture.

Participant 8 did not know whether the device would improve posture or not. The participant mentioned that for beginners, it could be difficult to adapt the posture based on the feedback. The feedback could bring the skaters out of balance which would make the posture of the skaters worse. Moreover, considering that the device does not measure how far a skater leans forward or backward, the knee angles could be improved by leaning forward, which does not improve the skating posture.

Next, the participants were asked whether they would use the wearable during inline skating. The results for this question are shown in Figure 8.6b. Thirteen participants mentioned that they would wear the wearable again. However, almost all participants mentioned that the device should not be used during every training session. The participants mentioned that it would be nice to use the device during training sessions in which there is a specific focus on posture. When the focus of the training is on other aspects, the device could be frustrating as the users themselves already know their posture is not correct but are too tired to adapt to the feedback. Four participants mentioned that they would use the device if there were less wires and if it was easier to put it on and off. Two participants mentioned that they would not use the device as they do inline skating for fun and not specifically to get better.

The participants were also asked what they thought about the device in general. The participants mentioned that the device made them more aware on their posture and that it was nice to get real-time feedback. Participant 7 mentioned: "During skating, I did not have to pay attention to staying low, as the device gave feedback if my posture was incorrect, which means that I could focus on other aspects". Moreover, some participants mentioned that the device was motivating when positive feedback was given, but when negative feedback was given multiple times in a row, it was demotivating and frustrated.

Most participants mentioned that they were not bothered by the vibration motors placed on the knee when they were not vibrating. Participant 4 perceived the vibrations as unpleasant, but the other participants mentioned that they were not bothered by it. Participant 3 mentioned: "The motor did not vibrate too hard or too soft. The vibrations were good". Two participants said during the interviews that motors on the knee sometimes vibrated too long. Participant 10 says about this: "I do not know if the motor vibrated multiple times or that the vibration was just very long, because sometimes I thought: "Yes, I know I have to go lower".

The vibration motors on the back were perceived as more subtle compared to the vibration motors on the knees, but the vibrations were still clear. The participants also mentioned that they enjoyed the 'pat on the back' as the positive feedback shows that the device is still working and it is motivating to know that the posture is correct. Participants 5 and 6 mentioned that the feedback on the back was not useful as the participant only received positive feedback.

With regards to the wearable, the participants found the wearable comfortable. However, two participants mentioned that the bands around the upper leg scraped against other leg during the step-over, which was uncomfortable. This was solved by adding tape to the upper bands. Moreover, the wires which went from the ESP32 to the knees were taped to the side of the upper legs of the participants, but this tape did not stick well which means that the wires were hanging loose around the legs. For two participants, the wires were too tight around the legs, which hindered movements. Most of the participants mentioned that the harness was fine and was not uncomfortable. One participant mentioned that the harness was a hassle to put on.

Lastly, the participants were asked what they would change about the design. Below, a list of suggestions given by the participants is written down. Behind each suggestion is written down how many participants have suggested the improvement.

- Create a wireless prototype or a prototype with less wires (5 participants)
- Add new sensors (4 participants) (suggestions: sensors to measure whether the hip is pushed in the corner, sensors to measure the hip angle and sensors to measure the ankle angle).
- Make an app where you can see how the posture changes during the training session. (3 participants)
- Change how the motors and sensors are integrated or make an integrated design so that the sensors and motors are integrated in pants or knee guards. (3 participants
- Move the vibration motors from the knee to the upper leg (2 participants)
- Change the calibration systems, so that it is easier to do or that it can be done dynamically (2 participants)
- Adapt the positive feedback signal, so it is more clear to which part of the posture the positive feedback signal belongs when feedback is given to multiple parts of the posture. (1 participant)

8.3 Conclusion

An evaluation test was performed to see whether the created wearable improved the posture during inline skating. The focus was specifically on keeping a round back and on making a low knee angle. The participants were asked to skate 5 trials of 4 minutes in which different feedback conditions were used. The data was analysed in a repeated measures ANOVA. The repeated measures ANOVA showed that there is a significance difference for intermediate skaters between the first and last no feedback trial, which indicates that participants get tired over the course of the experiment.

When the data is corrected for fatigue, the data show that the average knee angle is lower when feedback is provided to the knee compared to when no feedback is provided. The interaction effect between trials, experience and location show that intermediate inline skaters on the UTrack have a larger improvement in knee angle compared to advanced inline skater. This could be caused by the wide corners of the UTrack which makes it difficult to do proper cross over steps. For advanced skaters on other locations, there is a much larger improvement in knee angle which could be explained by the fact that these skaters were not influenced by the wide corners.

Next, the data of posture of the back was analyzed with the paired sign test. The tests showed that the posture of the back did not improve when feedback was provided compared to when no feedback provided. Based on the results of the experiment, the feedback does not improve the curvature of the back for the users.

Based on the interviews, most participants think that the device helped to improve their posture during inline skating and would use the device again during training sessions. The participants perceived the given feedback as pleasant and comfortable. The participants did mention points of improvements for the device. The most important points are: reduce the number of cables in the device, add new sensors to measure other parameters, and create an app so that it is possible to read out the data.

Overall, the data showed that feedback on the knees helps inline skaters to reduce their knee angle, while feedback at the back is not effective to improve the posture of the inline skaters.

Chapter 9

Discussion and Recommendations

It is difficult for trainers to provide real-time feedback during inline skating, due to the speed of inline skating and the size of training groups. Haptic feedback can help to provide targeted feedback to inline skaters. This study aimed to create a haptic wearable to coach inline skating posture. The study focused on three aspect; posture measurements, haptic feedback design and wearable testing. The discussion section discusses for each of these aspects the main findings, implications, limitations and recommendations for further research. The section ends with recommendations for the prototype.

9.1 Posture measurements

The experiments on posture measurements showed that the best way to measure the inline skating posture is to use inertial measurement units. To measure the knee angle, two inertial measurement units should be used; one placed above the knee and one below the knee, which was also found in other studies [6, 38]. Based on these findings, it seems that IMUs are effective to measure knee angle flexion and can be used in the development of other wearables.

The experiments on the posture measurements on the back showed that two inertial measurements were best to measure the curvature of the back. The experiment showed that two IMUs on the middle back was the best option to measure the curvature of the back. Nevertheless, the sensor could not distinguish between a round, hollow and straight back for all participants. Therefore, it is recommended to do more research on the best method to measure the curvature of the back.

One limitation of the knee angle measurements is that the measurements are not accurate when the inline skater is not straight above their inline skate. The software calculated the delta based on the x-axis of the accelerometer, which only works when the user stands straight on the support leg. This means that the measured average knee angle contains a measurement error. However, the data compares the trials in a within-subject design. It is assumed that the measurement error occurs similarly for each trials for one participants. Therefore, the measurement method was sufficient for this project. Due to the measurement error, it is not possible to make claims outside of this study based on the average knee angle. For future studies, it is recommended to improve the software to make the measurement of the knee angle more accurate.

The experiments showed that flex sensors lose precision over time. The bending of the flex sensor causes the sensors to break over time [39]. This makes the flex sensor unsuitable for wearable which should be used multiple times or for a longer period of time. However, the flex sensor seemed promising to measure the curvature of the back, which means that flex sensors can be useful for wearables. Therefore, further research can focus on the development of a durable flex sensor.

9.2 Vibrotactile feedback design

The experiments on vibrotactile feedback design found that the most intuitive location for haptic feedback is at the location where movement takes place. To provide feedback on the knee angle, the front of the knee was most intuitive and to stimulate a round back, the middle back was most intuitive. The finding that the vibration should be located at the location of the movement corresponds with the findings of Bark et al. [54]. This information can be taken into account for the design of other wearables and the design of haptic feedback.

Next, the study found that a single pulse on the knee and a directional pattern on the back were the most intuitive patterns according to the participants. Participants mentioned that a pattern with multiple motors was perceived as "too slow", while the pattern was shorter than the single pulse pattern. For the back, the directional pattern was not perceived as too slow, which could be explained by the fact that the legs move in a rhythmic motion while the back stays in the same location throughout inline skating. This suggests that for short, rhythmic motions a single pulse pattern is best while for non-rhythmic motions more complex patterns can be used.

The results of the experiments on haptic feedback add to the literature on the design of haptic feedback. This study, together with other studies focused on different parameters of vibrotactile feedback (e.g. [52, 56]), can help to create clear guidelines for the design of haptic feedback.

9.3 Wearable design

One of the strengths of the experiments is the used of iterative design. The use of iterative design made it possible to investigate different parameters and to improve the prototype based on the results of the experiments. A limitation of this method is that the small experiments were performed with a small number of participants (N=4). This means that it is difficult to draw strong conclusions based on the findings of the experiments. Therefore, the iterative method is recommended when there is a short period of time to develop a wearable. However, when there is more time, it is recommended to do more thorough research with larger sample sizes.

Throughout the experiments, it became clear that the coin motors are not strong enough for inline skating. The coin motors were not perceived well due to the background vibrations felt during inline skating. Cylindrical vibration motors are more suitable. Therefore, it is recommended to use cylindrical vibration motors for the design of wearables in sports, such as inline skating, where the are factors which influence the perception of vibrations.

9.4 Wearable testing

The evaluation test showed that the designed wearable was effective to improve the knee angle of inline skaters. This means that haptic feedback can be effective to improve posture in sports, which corresponds with findings of other studies [4, 5, 15].

The study compared the data of two trials; one at the beginning and one at the end, to evaluate whether learning or fatigue influenced the data. The data for the knee angle showed that participants performed better during the first trial compared to the last, which indicates fatigue. However, the fatigue did not occur for the data of the curvature of the back. This suggests that fatigue occurs more for the knee angle compared to the curvature of the back, which is expected considering that maintaining a low knee angle takes up a lot of energy.
Due to the fact that participants received feedback on their posture, learning could also influence the measurements. However, with the current study design it was not possible to determine which part of the difference between the two trials occur due to learning and which to fatigue. For future research, it is recommended to develop a test which can measure both fatigue and learning.

The evaluation test measured the knee angle of participants and found that the average left knee angle is higher compared to the right angle. It was suspected that this difference is caused by the corners in inline skating. Moreover, advanced inline skaters on the UTrack have a smaller improvement compared to advanced inline skaters on other locations, which suggest that the location and the bend radius has an influence on the average knee angle. This could be investigated in further studies.

Throughout the experiments, one participant also mentioned that they did not have to pay attention to their posture, since the device was already doing that. This could be both an advantage and disadvantage of the wearable. The advantage is that the device could allow the participant to fully focus on other technical aspect of inline skating, while still maintaining a correct posture. The drawback of this is that participants can become dependent on the feedback to maintain a correct posture [50]. Therefore, it is recommended to study what the frequency of feedback should be so that participants find the feedback useful, but do not become dependent on the feedback.

The study also found that the frequency and content of feedback influences the motivation for participants, which is as expected [50]. The wearable used a static calibration procedure to determine the feedback thresholds. When correct thresholds were set, the participants were motivated, but when the thresholds were set too strict, the participants got frustrated due to the negative feedback. This was also found in the study of Peeters et al. [4]. Therefore, to optimise the feedback, a dynamic calibration procedure is recommended. Dynamic calibration allows the system to calibrate during inline skating which is more accurate compared to static calibration.

A limitation of the wearable testing is that the tests have been performed on a set of participants who were mostly students and most participants came from the same inline skating association. This means that their skating technique is influenced by the provided training as most of the participants follow the same training. This means that the data is not strictly independent which was assumed for the repeated measures ANOVA. This could have influenced the results of the statistical tests.

9.5 Recommendations for the prototype

Based on the results of the evaluation test, there are recommendations for the prototype.

First, the prototype currently focuses on two factors of the inline skating posture; curvature of the back and knee angle. However, there are more factors of importance during the inline skating posture such as the hip angle. Therefore, it is recommended to test more parameters to see for which parameters haptic feedback can help to improve the inline skating posture. Parameters which could be tested are the hip angle, the ankle angle, and the posture of the hip in corners.

Second, it is recommended to store the data on a platform or app so that the users can gain insight on their measured knee angle over the course of a training and/or season. The app and stored data could allow the user to adapt the feedback threshold depending on the type of training, which makes it possible to alter the device per person.

Third, the hardware of the data contains of a lot of wires which hinder during inline skating. Therefore, the participants mentioned to reduce the number of wires in the device or to make the device wireless. The wearable could also be integrated into smart garments to make the wearable even more compact.

Lastly, different parameters such as frequency and intensity of the vibration motors, and frequency and content of feedback can be investigated to gain a deeper understanding of the different parameters influencing vibrotactile feedback.

Chapter 10

Conclusion

It is difficult for coaches during inline skating to provide real-time feedback to the skaters. Therefore, the aim of the research project was to create a wearable which can coach posture in inline skating using haptic feedback. The research focused on one research question and four sub-questions:

RQ: How to design haptic feedback for coaching posture in inline skating?

SQ1: What is the state-of-the-art of vibrotactile feedback in sports?

SQ2: What defines a correct posture in inline skating?

SQ3: How to measure a correct posture in inline skating?

SQ4: What parameters influence the design of effective haptic feedback?

With the help of all the sub-questions, the mean research question can be answered. Therefore, this chapter will go over each sub question first and answer the main research question in the end.

SQ1: What is the state-of-the-art of vibrotactile feedback in sports?

The context analysis in Chapter 2 provided a state-of-the-art overview of vibrotactile feedback in sports. Vibrotactile feedback has been applied to different sports such as cycling, mountain biking, golf, snowboarding, volleyball and squats. The studies show that vibrotactile feedback is well perceived during exercises and can improve performances. Vibrotactile feedback can fill gaps in the creation of wearables for an "average" athlete rather than specific athletes. This means that the wearables should be able to adapt to the users skill level. The state-of-the-art research found two researches focusing on skating. However, these projects did not investigate the best methods to provide vibrotactile feedback during inline skating. In conclusion, the state-of-the-art research shows that vibrotactile feedback has been applied to different sports and seems promising to improve performance.

SQ2: What defines a correct posture in inline skating?

In the context analysis in Chapter 2 the correct posture in inline skating was investigated. This was done using a literature research and by interviewing inline skating trainers. For a correct inline skating position, the knee and trunk angle are important to stay aerodynamic. The knee angle should be small (90 to 120) degrees, but depends on the time that the low knee angle should be kept. Keeping a low knee angle is tiring, which is why for short distances a knee angle of 80 to 90 degrees is best, but for longer distances a knee angle from 110 to 120 degrees is more suitable. Moreover, for a correct posture, the knees should be pushed forward so that the user does not fall backwards. Lastly, the pelvis should be tilted backwards to make a round back. This helps to reduce air resistance and allows the skater to make an effective push-off.

SQ3: How to measure a correct posture in skating?

Chapter 4 describes different experiments that were performed to determine which sensors can be used to measure the inline skating posture. The experiments compared inertial measurements units and flex sensors to measure the knee angle and curvature of the back.

The best method to measure the knee angle is to use two inertial measurement units. One IMU should be placed above the knee and one below. The sensors were placed on the outside of the leg so that the sensors do not hinder movement. The experiments showed that IMUs do not experience drift, are more accurate and have a higher sensitivity compared to flex sensors, which make them suitable to measure the knee angle.

To measure the curvature of the back, also two inertial measurement units can be used. The flex sensors seemed promising, but lost precision over time. The experiments on placement found that the curvature of the back is best measured when two IMUs are placed on the middle back. This means that to measure the complete inline skating posture, six inertial measurement units are needed. Two inertial measurement units for each leg and two for the back.

SQ4: What parameters influence the design of effective haptic feedback?

The parameters for effective haptic feedback design were explored in the literature research in Chapter 2 and through experiments. The literature research showed that haptic feedback is influenced by the design of feedback and by the design of the vibrotactile signals.

The design of feedback in motor learning is influenced by the timing of the feedback (concurrent or terminal feedback), the frequency of the feedback and the content of the feedback (positive or negative feedback). The design of vibrotactile signals in influenced by the type of vibration motor that is used, the placement of the actuators and used vibration patterns. The vibration patterns are described by the intensity of the signal, the used frequency and the duration of the pulses.

The design of the vibrotactile signals was investigated in Chapter 5, Chapter 6 and Chapter 8. The results of the experiments showed that a single pulse located slightly below the knee is most intuitive to make a low knee angle. To make a round back, a directional pattern on the middle back moving down is most intuitive. The evaluation tests showed that the feedback on the knees helps to improve the knee angle of inline skaters. However, the feedback on the back was not effective to improve the curvature of the back for inline skaters.

RQ: How to design haptic feedback for coaching posture in inline skating?

Throughout this research, a wearable has been created which provides haptic feedback to coach posture in inline skating. At first, a context analysis was done to get information on the state-of-the-art in haptic feedback in sports, how haptic feedback should be designed, what describes a correct inline skating posture, and how this posture can be measured.

Next, a series of experiments was performed to gain more information on how the inline skating posture can be measured and how vibrotactile feedback should be designed, with a specific focus on actuator placement and vibration patterns. Based on the results of the experiments, a prototype was made which provided vibrotactile feedback based on the posture of the inline skater to coach posture. This prototype was evaluated using an evaluation test. The evaluation test showed that the vibrotactile feedback does improve the knee angle, but does not improve the posture on the back. This could be caused by the fact that the users received more negative feedback for the knee angle compared to the back, which made the users adapt more to the knee angle compared to the back. The interviews show that most participants believe that the feedback improve their posture. Moreover, most participants would use the device again during training session focused on the inline skating. Therefore, it can be concluded that the designed wearable looks promising to coach inline skaters posture focused on the knee angle.

The study shows that haptic feedback can improve posture, but does not automatically work for all parameters of the posture. Haptic feedback should be carefully designed and the study added to the knowledge on the design of haptic feedback, specifically actuator placement and the use of different location patterns. The research showed that participants preferred feedback on locations where the change should take place and that short patterns are preferred over longer patterns. This knowledge can be used during the design of other haptic feedback devices in other fields of sports.

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Appendix A

Interviews on inline skating posture

Interview trainer 1

How long have you been skating yourself?
Good question. I have been skating for approximately 14 years. Maybe a little more.

How many years have you given training?
I have been giving training for three years now. I have only given training to a recreational group at a student association, as I joined the association and it became clear that my level was high enough to give training to the students.

What is the perfect inline skating posture according to you?
You have a 90 degree angle for the knees, in which your knees are placed above or in front of the toes. So that your hips are flat. Next, a round back is important so that you look forward through your eyebrows. This causes your shoulders, knees and toes to be in one approximate line. This is an efficient way to use your strength and to reduce frontal surface. You should also keep your weight on the back of your heels, as you can steer with the tips of your skates. Keeping your weight on your heels also gives you more agility.

What is most difficult for skaters with regards to posture? Mostly lowering the hips. People often think that people are quite low. Moreover, some people move forwards with their nose, which means that the weight shifts to the front which makes it harder to use your strength efficiently. However, staying low is hard for the upper legs, which is why many people move slowly up. So I think that is most difficult for skaters. So stay with the weight on the back and push the knees forward.

How do you provide feedback during trainings?
I divide the training is blocks. First the warming-up, then a part technique and lastly a part strength. After the warming-up, I try to provide the skaters with theory and with a good example. Then I give them an exercise and provide feedback after the exercise on what went well and what did not well. During the exercise I sometimes tell the skaters to stay low.

Do you think haptic feedback can help to improve inline skating posture?
I think if the posture of the skaters is already quite good, the feedback can be a nice reminder if you are getting tired. So if you move slowly upwards, the feedback can remind you to stay low. However, I think that if you are a beginner and you are trying to learn to posture, that it can be very tiring. Because you keep getting reminders that you posture is wrong. That is also not motivating.

Is there anything you would like to add?
I would say look at individual time trials in inline skating. The time trials are 300m long and take approximately 23 seconds. For skating, Joey Mantia has a very good technique and posture, so you could look at him. Joey Mantia introduced the double push and has a very nice technique. If you look at other competitions in which skaters ride in a peloton, the posture is less important as you try to save some strength and come over the finish first. But in individual time trials, posture is very important. The brother De Souza also have a nice technique.

Interview trainer 2

How long have you been skating yourself?
“Since 2013, so 9 years”

How long have you been giving inline skating training?
“I give inline skating training for 3 years now. For speed skating, it is since 2014 that I give training to children. So for 8 years.”

How would you describe the ideal posture for inline skating?
“For which discipline? Marathon, track, tour skating? For the track, I think that the goal is to stay as compact as possible, since competitions on a track only take a couple of laps. For marathon or tour inline skating the knee angles can be larger, so that it is easier to keep the position. But in all disciplines, the essence is the same; sit deep with the legs, so push your knees forward and your hips down, so that you can straighten your leg fully during the push off. For a track position, you should be able to do a cross over, while during marathon and touring you might be able to keep up without being able to do a cross over. With touring and marathon, your upper body is also higher compared to during a track race.

But if you flatten your upper body you have less air resistance?
“True, but that is also heavy for your lower back muscles, so you must find a balance between what can you keep up and what reduces air resistance.”

What are ideal angles for a track race?
“That is difficult, because if I compare it to ice skating, you can have deeper knee angles for a 500 meters, compared to the last round of a 1000 meter. That is also the case for skating. For very short distances, the angle should be as low as possible. So for short distances approximately 80 degrees up to 110 and 120 degrees for marathons.

In what ways can the posture be done incorrectly?
“Having a too large knee angle, pushing your skate backwards instead of sidewards, but I do not know if that is part of the posture. Moreover, not being able to stand on one leg, so putting your weight on one leg is important. So that you are not with your weight between your skates. It is important for your posture that you can shift your weight to one leg and move it to the other side so you can push off. Other things are not being able to stay low or not being able to make a round back. If you cannot make a round back, you tilt your pelvis incorrectly making it more difficult for you to push off. So that.

What are difficult aspects for posture for inline skaters?
I find that very difficult. It depends on the level of the inline skaters and it depends on the discipline of skating. But one difficult thing is staying low, so to bring your knees forward and your hips down. If you only go through your knees, but do not bring your knees forward, you will fall backwards. Some people cannot or dare not to do that. Another thing is to come with your full weight above one skate.

How do you currently give feedback to improve posture during inline skating?
I give people exercises.

What kind of exercises, for example for moving your knees forward?
First do it while standing still, so push your knees in front of your toes standing still, then do it while rolling, later while performing the complete skating motion. This is an internal stimulus to feel how you should move your knees forward. You could also use an external stimulus, by doing a limbo dancing exercise, where people should roll underneath a stick. If your knees are not pushed forward enough, you will fall. So with this you force someone to push the knees forward.

Do you think that vibrations can help to improve your posture?
I think that it can be useful. As a coach, you can only focus on one rider in the group or on the whole group, but you only see them once over 400 meter. So I think it is beneficial to provide real-time feedback. However, then you should know beforehand what the vibration should mean. So is a vibration on your leg that my knees should move forward, my hips should go down or that my pelvis should tilt more? Which of the three does it mean. That should be clear. And how do you measure something.

For example, if you measure knee angle and during a push off a vibration is given that your knee angle is too large, that does not make sense since you have to straighten your leg during a push off. So the measurement should be done over multiple actions. If someone makes one mistake, that can happen. I think that it might be difficult to measure this. You could measure over a couple of strokes and detect the minimum angle over those strokes and provide feedback on that.

Is there anything you would like to add on the inline skating posture?
I want to say that this is my perspective as an ice skating practice. The inline skating practices I provide are more like ice skating on roller skates compared to inline skating. I did not get education to be a inline skate coach, instead I use my expertise as ice skating trainer to make people faster in inline skating to make them better ice skating, not to ride inline skating competitions. There are aspects which are used in inline skating which are not used in ice skating, such as the double push. So I will not focus on teaching my students how to do a double push, as it is not beneficial for ice skating.

Appendix B

Ethical procedure

Information Brochure

Background

Technology is getting more and more common in Sports. Think about a Garmin Smartwatch, time registration systems and sensor suits to measure the optimal movement.

At the University of Twente, research is done to the use of haptic feedback to enhance posture. Haptic feedback is feedback provided to the skin, such as vibrations or temperature. This research makes used of vibrotactile feedback, which uses vibration motors to the skin. The vibration motors feel similar to a vibrating phone.

The aim of the research is to create a haptic wearable which can improve posture during inline skating.

Haptics for Posture improvement in inline skating – March-2022

INFORMATION BROCHURE

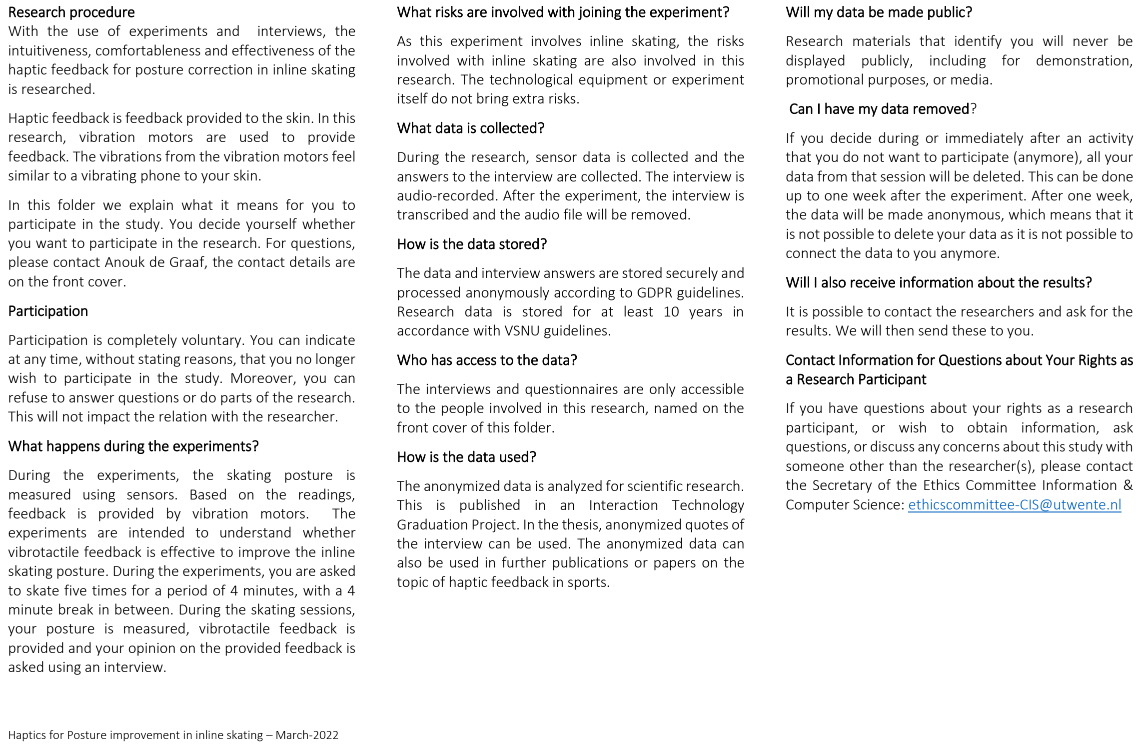
DESIGNING HAPTIC FEEDBACK TO

COACH POSTURE IN INLINE SKATING

In this brochure is information for the graduation project for haptic feedback design in inline skating. The brochure can help to decide whether you want to join the research or not.

Anouk de Graaf – a.j.m.degraaf@student.utwente.nl
Judith Weda Msc. –j.weda@utwente.nl
dr. Angelika Mader - a.h.mader@utwente.nl

Figure B.1: The first page of the Information Brochure



Research procedure

With the use of experiments and interviews, the intuitiveness, comfortableness and effectiveness of the haptic feedback for posture correction in inline skating is researched.

Haptic feedback is feedback provided to the skin. In this research, vibration motors are used to provide feedback. The vibrations from the vibration motors feel similar to a vibrating phone to your skin.

In this folder we explain what it means for you to participate in the study. You decide yourself whether you want to participate in the research. For questions, please contact Anouk de Graaf, the contact details are on the front cover.

Participation

Participation is completely voluntary. You can indicate at any time, without stating reasons, that you no longer wish to participate in the study. Moreover, you can refuse to answer questions or do parts of the research. This will not impact the relation with the researcher.

What happens during the experiments?

During the experiments, the skating posture is measured using sensors. Based on the readings, feedback is provided by vibration motors. The experiments are intended to understand whether vibrotactile feedback is effective to improve the inline skating posture. During the experiments, you are asked to skate five times for a period of 4 minutes, with a 4 minute break in between. During the skating sessions, your posture is measured, vibrotactile feedback is provided and your opinion on the provided feedback is asked using an interview.

What risks are involved with joining the experiment?

As this experiment involves inline skating, the risks involved with inline skating are also involved in this research. The technological equipment or experiment itself do not bring extra risks.

What data is collected?

During the research, sensor data is collected and the answers to the interview are collected. The interview is audio-recorded. After the experiment, the interview is transcribed and the audio file will be removed.

How is the data stored?

The data and interview answers are stored securely and processed anonymously according to GDPR guidelines. Research data is stored for at least 10 years in accordance with VSNU guidelines.

Who has access to the data?

The interviews and questionnaires are only accessible to the people involved in this research, named on the front cover of this folder.

How is the data used?

The anonymized data is analyzed for scientific research. This is published in an Interaction Technology Graduation Project. In the thesis, anonymized quotes of the interview can be used. The anonymized data can also be used in further publications or papers on the topic of haptic feedback in sports.

Will my data be made public?

Research materials that identify you will never be displayed publicly, including for demonstration, promotional purposes, or media.

Can I have my data removed?

If you decide during or immediately after an activity that you do not want to participate (anymore), all your data from that session will be deleted. This can be done up to one week after the experiment. After one week, the data will be made anonymous, which means that it is not possible to delete your data as it is not possible to connect the data to you anymore.

Will I also receive information about the results?

It is possible to contact the researchers and ask for the results. We will then send these to you.

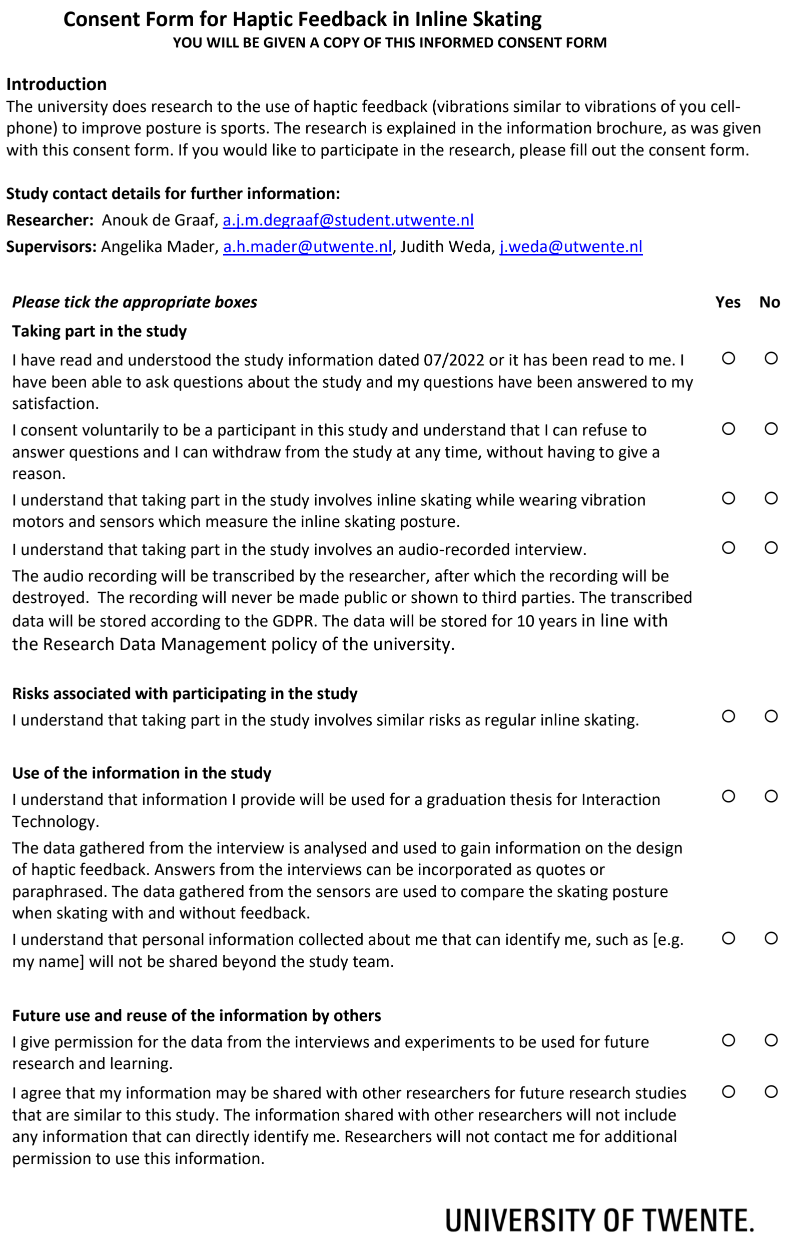
Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

Haptics for Posture improvement in inline skating – March-2022

Figure B.2: The second page of the Information Brochure

Consent Form



Consent Form for Haptic Feedback in Inline Skating

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Introduction

The university does research to the use of haptic feedback (vibrations similar to vibrations of you cell-phone) to improve posture is sports. The research is explained in the information brochure, as was given with this consent form. If you would like to participate in the research, please fill out the consent form.

Study contact details for further information:

Researcher: Anouk de Graaf, a.j.m.degraaf@student.utwente.nl

Supervisors: Angelika Mader, a.h.mader@utwente.nl, Judith Weda, j.weda@utwente.nl

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 07/2022 or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves inline skating while wearing vibration motors and sensors which measure the inline skating posture.	○	○
I understand that taking part in the study involves an audio-recorded interview.	○	○
The audio recording will be transcribed by the researcher, after which the recording will be destroyed. The recording will never be made public or shown to third parties. The transcribed data will be stored according to the GDPR. The data will be stored for 10 years in line with the Research Data Management policy of the university.		
Risks associated with participating in the study		
I understand that taking part in the study involves similar risks as regular inline skating.	○	○
Use of the information in the study		
I understand that information I provide will be used for a graduation thesis for Interaction Technology.	○	○
The data gathered from the interview is analysed and used to gain information on the design of haptic feedback. Answers from the interviews can be incorporated as quotes or paraphrased. The data gathered from the sensors are used to compare the skating posture when skating with and without feedback.		
I understand that personal information collected about me that can identify me, such as [e.g. my name] will not be shared beyond the study team.	○	○
Future use and reuse of the information by others		
I give permission for the data from the interviews and experiments to be used for future research and learning.	○	○
I agree that my information may be shared with other researchers for future research studies that are similar to this study. The information shared with other researchers will not include any information that can directly identify me. Researchers will not contact me for additional permission to use this information.	○	○

UNIVERSITY OF TWENTE.

Figure B.3: The first page of the Consent Form

Signatures

______________________ ______________________ _________
Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ___________________ _________
Researcher name Signature Date

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Figure B.4: The second page of the Consent Form

Appendix C

Interviews actuator placements

The transcription is divided into two sections; legs and torso. The leg section describes the experiment of the 9 locations on the legs and the torso for the 6 locations of the torso.

Legs

Upper legs

P1: “Ik vind 2 het meest chill en intuïtief. Aan de zijkant van je been heb je idee dat je iets moet doen. Bij 1 en 3 zit die op je spieren en zeker bij 3 heb ik het idee dat ik omhoog moet, omdat er vanonder iets trilt terwijl je juist moet inzakken. 1 vond ik niet super chill. 2 vond ik logisch voelen. Dat gaf meer de instructie van: je moet iets doen met dit been, niet perse met de voorkant of de achterkant. 3 vond ik ook het minst comfortabel omdat die op een rare plek zit achter je been, want dat geeft mij het idee dat ik omhoog moet. Daarom vind ik 2 het meest intuïtief en comfortabel. Ik zou voor 2 gaan en nummer 1 en 3 staan een stuk lager dan dat.”

P2: “Ik vond de bovenbenen wel chill. Ik vind het wel moeilijk om te zeggen wat fijner is. Ik vond ze eigenlijk alle drie wel comfortabel. Het meest intuïtief vond ik achter. Dus dat is 3, daarna 2 en 1. Ze voelde allemaal wel prima, dus hier ga ik ook voor 3, 2 en 1. Maar niet met een hele goede reden dat 1 beter is dan de ander.”

P3: “Het minst comfortabel is de motor op de hamstring. Deze motor irriteert en zit er zonder dat hij iets toevoegt. De motor aan de zijkant is het meest comfortabel. Voor mijn gevoel zit hij niet in de weg. De motor aan de voorkant zit net iets minder comfortabel. Ik vind de motor aan de zijkant het meest intuitief. De motor aan de achterkant heb ik het idee dat ik omhoog moet omdat die kietelt. Die aan de voorkant voelt alsof dat niet de juiste spieren zijn om op te focussen, dus vind ik minder intuitief. ”

P4: “Dus 1, de voorkant van het bovenbeen vind ik het meest bijdragen aan een betere houding, maar wel het minst comfortabel. Aan de voorkant heb ik het gevoel dat ik naar beneden wordt gedrukt. Ik heb het gevoel dat waar de trilling vandaan komt, dat daar gedrukt wordt, dus dan denk ah ik moet mijn bovenbenen naar beneden doen voor een kleinere kniehoek. Voor de achterkant had ik dat ook wel. De zijkant deed voor mijn gevoel niet veel voor mijn bovenbeen dus ging ik er niet dieper van zitten. Qua comfortabelheid vind ik de achterkant wel comfortabel. De zijkant doet niet zoveel. De bovenkant voelt niet zo heel chill, maar je gaat er wel dieper door zitten. ”

Knees

P1: “Ik vond 4 voor op mijn knie het chillst en het meest intuitief. Je knie is uiteindelijk toch het geen waarmee je het diepste gaat zitten en dit voelt toch als een herinnering. De zijkant voelde een beetje gek en daarmee dacht ik niet, nu moet ik dieper zitten of nu moet ik ergens op letten. In je knieholte is echt raar, dus dat is niet zo chill. Dus 4 is het meest comfortabel en intuitief. Dan 5 en dan 6. Op je achterbeen vind ik echt het minst handig en intuitief. Het zit gewoon net niet lekker omdat je in een diepe kniehoek moet zitten. “

P2: “Ik vond ze alle drie heel vergelijkbaar. Je voelde wel dat het net een andere plek was, maar het was allemaal een beetje hetzelfde. Ik denk dat ik de zijkant fijner vond, die was meer intuitief, maar misschien voor diepzitten vind ik de achterste wel meer intuitief. En dan daarna 5 en 4. Voor comfortabel maakt het eigenlijk niet uit. Maar dan zeg ik 5, 6, 4. Ik vond het meer intuitiever om het aan de achterkant te hebben, want dat beweeg je naar mijn idee.”

P3: “De zijkant is het meest comfortabel, ik heb het gevoel dat hij het minst in de weg zit en als die trilt stoort hij het minst. De voorkant is daarna het meest comfortabel, want die zit minder in de weg dan die in de knieholte. Je probeert een 90 graden hoek te maken en dan zit de motor in je knieholte in de weg. Het meest intuitief om dieper te zitten is denk ik aan de voorkant. Daar voel ik hem beter en dan wordt ik er beter aan herinnert om diep te zitten dan op de zijkant. Die in de knieholte stoort eigenlijk alleen maar.”

P4: “Met de motor voor ging ik het diepste zitten, met de motor in je knieholte het minst. Zijkant en achterkant van de knie vind ik allebei niet zoveel doen. Dus 5 en 6 is een beetje gelijk. Ik weet niet of je comfortabel moet omschrijven als het tegenovergesteld van intuitief, maar waardoor je dieper gaat zitten is niet perse comfortabel. Maar ik vind de trilling in de knieholte het chillst. De zijkant en voorkant maakt niet zoveel uit voor mijn gevoel. Maar dan denk ik dat de voorkant fijner is dan de zijkant. ”

Lower legs

P1: “Ik vond ze eigenlijk allemaal niet zo intuitief. Ik dacht nu niet van nu moet ik iets met mijn kniehoek gaan doen omdat het iets verder van je kniehoek af is. Zelf heb ik ook het idee dat als ik mijn bovenbeen voel dan denk ik, oh ik moet mijn bovenbenen naar beneden doen om dieper te zitten. Bij mijn onderbeen denk ik niet, ik moet mijn onderbeen verder naar voren doen om dieper te zitten, wat natuurlijk wel zo is. Dat is minder logisch dan op je bovenbeen. Verder maakt het mij kwa motor niet zo erg uit. Ik vond 8 iets minder fijn, maar ik vond het allemaal niet intuitief. Tussen 7 en 9 heb ik geen voorkeur.”

P2: “9 is je kuit, die vond ik het meest comfortabel. Die vond ik ook het meest intuitief. Je kuit is wat zachter en zit wat meer achterop. Dan trilt ook wat meer mee voor mijn idee. Dan trilt de hele spier mee en dan heb je het idee van: oh er trilt wat. Die aan de voorkant (motor 7) zit een beetje ongemakkelijk, die vond ik niet chill. Dan zit 8 ertussen in. Voor het meest intuitief vind ik niet dat er veel verschil in zit, omdat het op dezelfde hoogte zit. Dus dat vind dezelfde volgorde als met comfortabel.“

P3: “Die op het scheenbeen vond ik het minst comfortabel. Tussen de zijkant en de kuit kan ik weinig onderscheid maken tussen hoe comfortabel het zit. Het is beide wel prima. Als ik moet kiezen denk ik dat de kuit toch wel comfortabeler zit. Het meest intuïtief is degen aan de zijkant. Dat voelt wel oke. Aan de voorkant merk ik het niet zo goed en als ik het voel dan stoort het. De kuit kietelt ook een beetje, dat is ook een andere spiergroep dan die je gebruikt om dieper te zitten voor mijn gevoel.”

P4: “Ik had vooral gelet door welke trilling ik meer diep ging zitten. Door de trilling aan de voorkant ging ik meer achterop zitten voor mijn gevoel. Als ik hem aan de achter kant voelde, dan denk je: “ik moet naar voren” omdat je voor je gevoel een beetje een druk die kant op krijgt. Ik denk dat ik in het algemeen niet goed achterop zit, dus daarom denk ik 7. De trilling aan de achterkant zit het chillst, want daar merkte je het minst van, maar daardoor denk ik ook dat het niet echt helpt.”

Comments during ranking

P1: “Ik vond die band om mijn knie niet zo handig, maar ik vond motor 4 wel intuitief omdat het wel op de locatie is waar je dieper moet zitten. Het was niet perse comfortabel. Dus ik zet 4 op meest intuitief, en 2 daarna. Maar 2 is comfortabeler dan 4. Het voornaamste dat 4 niet comfortabel is, is door de band die je nu om doet. 1 is wel prima en intuitief. 5 was ook nog wel oke. 6 was echt raar en 3 op je achterbeen was ook niet fijn. Dus die plaats ik wat lager. Kwa intuitief verliezen 7, 8 en 9 sowieso. Ik vond je hamstrings minder intuitief dan je knieholte, maar 7, 8, 9 zijn wel comfortabeler denk ik, want het is gewoon raar als je iets achterop je been krijgt.”

Participant 2 did an extra test during ranking to compare the motor on the knee to the motor on the calf.
P2: "Ik vond de achterste toch het intuitiefs, maar ik wilde even kijken welke plek logischer is. Ik vind wel dat je knie het meest logisch is omdat je daar het meeste mee buigt. Dus als je daar een tril voelt, dan denk je: oh ja ik moet mijn knie buigen. Als je het ergens anders voelt, dan moet je weer gaan nadenken van: oh ik moet mijn knie buigen. Dus bij de knie is intuitiever. En dan 3 en dan 9. Daarna zijn de zijkanten intuitief en als laatste de bovenkant. Voor comfortabel vind ik dat de motor aan de voorkant van het onderbeen niet comfortabel was, dus die gaat onderaan. De rest voelt niet heel vervelend dat er iets zit. Ik denk dat 9 het meest comfortabel was, daarna 3 en 6, maar 6 voelde je wel beter dan 3. Ik weet niet of dat is omdat je knie gevoeliger is voor trillingen of doordat de motor misschien sterker is. Daarna komen 1 en 2. Dan 8, 5 en 4."

P3: "Het meest comfortabel was nummer 2, daarna 5 en 8. Aan de achterkant stoorde die het meeste, waarbij het knieholte het allermeest, daar zit die in de weg. Daarna denk ik de kuit, dat voelt ook niet lekker. De middenmoot is allemaal een beetje vergelijkbaar kwa comfort. Zijkant bovenbeen, was meest comfortabel. Het meest intuitief is de zijkant van je knie, dan zijkant bovenbeen. Het minst intuitief is de hamstrings en dan de knieholte. Voor op de knie vond ik ook niet zo intuitief. Van trillingen op de kuit ging ik ook niet echt dieper zitten. "

P4: "Sowieso vond ik de bovenbeen het meest hielp om dieper te zitten. (1 en 3) en daarna bij de knie aan de voorkant. En dan 7, de voorkant van het onderbeen. De zijkant bij de kuit deed niets, dus die mag onderaan. Verder weet ik het niet zo goed eigenlijk. Voor mijn gevoel maakte het niet echt uit. Want het deed allemaal niet zo heel veel. Aan de voorkant wel maar de rest niet echt. "

Participant 4 tested motors 5, 6, 8 and 9 again before completing the ranking.

P4: "Door knie achter ging ik niet echt dieper zitten. Van onderbeen achter ging ik wel dieper zitten vond ik. Door de zijkanten allebei een beetje, maar ik denk dan wel zijkant knie iets meer dan zijkant kuit. Qua comfortabelheid vond ik motor 3 het meest comfortabel. Ik vond die achter in mijn knie ook wel erg comfortabel. De zijkant was gewoon middenmoot. Ik vond qua comfortabelheid de motoren rond mijn bovenbeen wel iets comfortabeler. 5 en 8 waren allebei matig comfortabel.

Torso

Upper torso

P1: "Hmm, je voelde 10 gewoon wat beter dan 11. Maar ik vond ze allebei niet heel intuitief voor een bolle rug denk ik. Ik denk dat 11 comfortabeler was dan 10, maar 10 was intuitiever dan 11."

P2: "Die onder je sleutelbeen vond ik intuitiever, weer hetzelfde als ik heb verteld bij middle torso en lower torso. Het meest comfortabel maakt niet zo veel uit. Het zit niet op een gekke plek ofzo. "

P3: "Beide zijn minder comfortabel en intuitief dan de middle en lower torso. Van de voorkant merkte ik weinig omdat het los in het shirt trilde. Dat kietelde meer dan dat het iets deed. Het had voor mijn gevoel ook niet veel te maken met het maken van een bolle rug. Achter zit iets comfortabeler dan aan de voorkant en doet het iets meer voor het maken van een bolle rug, maar nog steeds niet heel veel. "

P4: "Nu is het een beetje andersom. Die op je rug duwt je wat meer naar beneden, dus nu vind ik je rug beter voor je bolle rug. Die op je buik duwt je een beetje omhoog. Dan heb je ook niet dat je buikspieren trillen, dus dat je denkt: "oh nu moet ik wat doen". Ook qua comfortabelheid vond ik het zo, want ik vond die op je buik niet zo heel comfortabel."

Middle torso

P1: "Je buik voelt alsof je gekieteld wordt, maar dan heb je niet het idee alsof je iets moet gaan doen (12). Bij 13 dacht ik wel, oh ik moet even op mijn rug letten."

P2: "Ik vond op mijn buik intuïtiever omdat je je buik klein moet maken. Ze zaten allebei niet in de weg, dus ik denk dat je je buik duidelijker voelt. Ik kan niet echt beargumenteren waarom. "

P3: “De buik is in beide gevallen minder comfortabel en minder intuïtief dan de rug. Bij de buik voelt het in de weg en ik heb het gevoel dat alles van mijn buik tot zaakje begint met trillen. Op de rug zit het minder in de weg en krijg ik gelijk het idee dat ik mijn schouders ontspannen moet houden en naar voren trekken zodat mijn rug bol wordt.”

P4: “Hier vond ik het heel duidelijk. Het deed allebei een beetje maar niet heel veel. Op je buik heb je wel een beetje buikspieren, maar volgensmij houden je buikspieren eronder al op. Je kreeg wel een beetje dingen in je rug. Ik vond die op je rug wel een lekkere massage, was wel heel comfortabel eigenlijk. Ik vond het wel lekker. 13 was sowieso meer comfortabel dan 12. Ik denk ook dat 13 meer intuïtief was dan 12, maar er is maar een klein verschilletje.”

Lower torso

P1: “Bij alles op de voorkant heb ik het idee dat ik mijn buik omhoog moet doen. Van de trilsensoren krijg ik het idee dat als die op je rug zit, dat ik naar beneden moet en als die op de buik zit dat ik omhoog moet. Je buik kietelt vooral, maar heeft niet heel veel invloed. Dus 14 is minder intuitief. Comfortabel zijn ze allebei wel.”

P2: ‘Die aan de voorkant vond ik het meest intuitief. Als ik iets aan de achterkant voel, heb ik de neiging om mijn rug recht te doen. Als ik het voor voel heb ik de neiging om mijn rug meer bol te maken. Dus 14 is het meest intuitief. Op mijn rug voelde ik de motor minder. Je voelde wel wat, maar als je er niet op letten had het net zo goed niet zo kunnen zijn. Dus voor comfort en gebruiksgemak is 14 beter.”

P3: “De rug zit meer comfortabel. Je probeert je rug bol te maken, dus dan zit de motor op de voorkant een beetje bekneld. Maar de motor op de voorkant is wel intuïtiever omdat je je bekken moet kantelen om een bolle rug te creëren en daar helpt dit wel bij.”

P4: “Ik vond die dingen in je buik echt niet comfortabel. Dus 14 is niet comfortabel en 15 wel. Maar bij 14 dacht ik wel: “Ik moet mijn buikspieren aanspannen”, dus het is wel goed voor je bolle rug. Dus dat is mijn redenatie.”

Comments during ranking

P1: “Ik denk dat ik 13 in het midden van het rug het meest intuïtief vond. Dat zat wel op een logische plek. Daarna was 15 het meest intuïtief. De rest vond ik wel een stuk minder intuïtief. Ik denk dat ik 12 intuitiver vond dan 14 en 10 en 11 vond ik ook niet heel intuitief, maar wel meer dan wat op mijn buik zat. Kwa comfortabelheid vond ik ze allemaal wel prima, maar van dingen op je buik ga je gewoon een beetje lachen want dat kietelt. Op mijn schouderbladen vond ik ook niet heel chill.

P2: “Het meest intuïtief vond ik de motor op je navel. 12 was het meest intuitief. Daarna die op je bovenlichaam (10) en daarna 14. Daarna 13, daarna 15 en daarna 11. Ik vind je navel het meest intuitief omdat het in het midden van je buik zit en dus het main ding is waarmee je je rug bol maakt. En voor is meer intuitief dan achter. Meest comfortabel vind ik ook je navel.”

P3: “Least comfortabel is 12. Daarna 10 en dan 11. Het meest comfortabel is 13 of 15, maar ik denk dat 13 comfortabeler is dan 15. Dan is 14 over in het midden. Het meest intuïtief is denk ik 14 en dan 13. Het minst intuïtief vind ik 10 en 11. 12 en 15 zitten in de middenmoot. Da nis 12 minder intuïtief dan 15.”

P4: ”Sowieso is die buikspier massage het beste om een bolle rug te maken, dus dat is 14. 15 vond ik echt het minste. 12 en 13 vond ik een beetje gelijk. 11 duwde in je rug, die had ik net ook hoog, dus die doe ik daarna. 10 vond ik wat minder. 12 en 13 maakt niet zoveel verschil, maar aangezien ik net 13, 12 zijn doe ik dat ook. Kwa comfortabelheid vond ik 13 echt lekker. In je buik (14) vond ik niet comfortabel, maar wel goed voor je buikspieren. 15 was een beetje neutraal. 13 en 12 vond ik allebei wel prima comfortabel en daarna doe ik 15, 11, 10. Die in je rug zijn wel lekker.“ Bij 14 denk ik wel: “Ah komt die weer”, maar daarvan ga ik wel dieper zitten. Voor 3 passen was het prima, maar bij 20 passen zou ik wel denken: “Ik wil niet meer dat die komt”.

Appendix D

Interviews conceptual mapping

Preference for push or pull

P1: “Als de achterkant van mijn been trilt, heb ik het idee dat ik omhoog moet, dus dat is een “pushed away” van de trilling. Dus dan denk ik, dan moet ik met mijn been omhoog. Als die aan de voorkant zat, dacht ik: oh nu moet ik met mijn been naar beneden. Met mijn rug had ik hetzelfde, maar omdat je weet dat het gericht is op een bolle rug, oh ik moet mijn rug wat naar achter doen, waardoor je je kont beter draait waarom je een bolle rug hebt. Voor de rug vind ik het lastig, maar bij het midden van de rug ga ik er naar toe, dus dan is het meer een “pull” beweging. Op mijn buik had ik wel het idee dat ik mijn buik omhoog moest doen, dan had ik het idee nodig dat er meer ruimte nodig was bij mijn buik, dus dan gaat het er vanaf.

P2: “Als ik een trilling voel heb ik het gevoel dat ik die spier moet aanspannen. Dus wel meer dat ik ernaar toe moet bewegen. Als hij op de bovenkant van mijn bovenbeen zit, dan denk ik dat mijn bovenbeen omhoog moet. Dus ik vind dat een motor “pulls towards” een beweging.

P3: “Op mijn hamstrings had ik het idee dat ik ervan af moest bewegen, maar aan de zijkant dacht ik wel dat ik moest inzakken. Op mijn bovenbeen had ik minder het idee dat ik moet inzakken. Voor mij was de zijkant het logisch, maar dat is niet echt een antwoord. Voor mijn gevoel wisselt het per locatie. Maar ik denk dat ik eerder van de motor af beweeg dan er naar toe. ”

P4: “Bij de meeste trillingen dacht ik dat die mij een soort van duwde, dus ik moet er vanaf bewegen. Maar bij de buikmassage had ik dat juist weer niet. Nou eigenlijk ook er vanaf want je gaat je buikspieren aanspannen. Dus over het algemeen er vanaf.

Follow me vs push/pull - Legs

P1: “Ik denk wel gewoon alleen bovenbeen. Die in je knie is iets te traag. Dan begint de bovenste met trillen en de onderste begint pas met trillen als je bijna op je andere been staat. Terwijl je wilt je kniehoek kleiner maken als je alleen op dat been staat en in de swing fase bent voor de afzet. Dan wil je vlak voor je afzet de kleinste kniehoek hebben want dat heeft het meeste effect. Daar ben je nu iets te laat mee, dus ik denk dat hij iets te langzaam is. Verder voelde het alsof er een waterdruppel langs je been gleed. Ik denk dat het wel kan werken, maar ik had ook het gevoel alsof deze iets minder sterk was. En het zit in je knieholte, dus je gaat automatisch minder diepzitten omdat het in je knieholte zit. Dus ik denk dat het kan werken, maar het heeft wat aanpassingen nodig. De voorkeur voor nu was wel de motor mijn bovenbeen. ”

P2: “Ik vond de “follow me” wel intuïtief, alleen hij gaat te langzaam voor een statische schaatspas. Misschien als je skeelert dat die wel goed gaat. Het is jammer als je signaal langer duurt dan dat je op dat been staat, want dan heb je er net niets aan. Ik vond dit wel intuïtiever, omdat je wel alle drie doet en dat is wel meer de beweging die je ook doet met je been.”

P3: “De voorkant vond ik fijner, puur omdat het 1 signaal is in plaats van meerder signalen. Dat heeft ook te maken met de timing van de signalen. Ik was al bijna klaar met de pas voordat de tweede helft van het signaal kant. Ook vind ik het aan de achterkant meer in de weg zitten dan aan de voorkant, dus dan stoort het meer dan dat het helpt. De tape aan de voorkant was wel vervelend, omdat het opgeplakt was terwijl mijn been gestrekt was en ik het daarna ging buigen ;)"

P4: "ik snap het idee wel hiervan. Eigenlijk helpt het allebei. Ik vind de bovenbeen nog steeds helpen, want dan denk ik je: "Ik moet mijn bovenbeen naar beneden duwen". En die in je knieholte laat je denken: "Ik moet mijn knie naar voren duwen". Eigenlijk helpen ze dus allebei dus als je ze allebei doet helpt het misschien dubbel. Ik vond die op de bovenbeen toch iets fijner, maar dat is meer omdat ik meer mijn bovenbeen naar beneden moet duwen dan mijn knieën naar voren bij mijn eigen schaatshouding. Terwijl als je meer je knie naar voren moet duwen, dan helpt die ander juist meer. Dus voor mij was die op de bovenbeen meer intuïtief, maar het patroon op je knie helpt wel.

Follow me vs push/pull - Back

P1: "Ik vond het fijnst als alleen mijn rug trilde. Met voor en achter was ik aan het nadenken, want dan voel ik een trilling en dan trok ik mijn buik in en dan voel ik nog iets. Het klopt wel volgensmij en het effect was ook goed dat ik mijn buikspieren aanspande en mijn rug bol maakte, maar het voelde gewoon heel raar. Ik moest er wel veel over nadenken, misschien is dat juist wat je wilt. Ik vond alleen mijn rug, dacht ik, ik moet aan mijn rug denken. Door deze combinatie wist ik wel precies wat je wilde met een bolle rug. Ik weet het niet helemaal. Maar het voelde niet intuitief, het was meer van: "wat gebeurd hier? Oh ik ziet dieper". Als ik moet kiezen zou ik dan wel liever alleen trillingen op mijn rug hebben. Dus dat is pull. "

P2: "Ik vond het logischer om er maar 1 te hebben. Als je er twee had, was het verwarrend dat je eerst iets naar achter moet doen en daarna naar voren. Dus ik vind 1 logischer. Dat vind ik meer intuïtief."

P3: "Het meest intuïtief vind ik de dubbele, maar aan de achterkant voelde ik hem veel sterker dan aan de voorkant, maar aan de voorkant zat die niet strak tegen mijn huid aan, dus misschien dat het anders zou zijn als ik een strak shirt aan had. "

P4: "Ik vond alleen de buik het meest intuïtief om dieper te zitten. Voor de follow me voelde ik hem bij de ene pas in mijn rug en daarna in mijn buik. Bij die in je buik was het constant en wist je wat er ging komen, dus dat vond ik fijner."

Appendix E

Interviews vibration patterns

Comments during ranking

Legs - Trial 1: Single pulse motor 2 and 3

P1: “Ik vond de tweede, (pattern 2) fijner die wat meer aan de onderkant zat. De andere zat meer op mijn knieschuif, waar je door je knieën zou gaan. Dan zit het op de plek wat ook moet veranderen, dus daaronder vond ik fijner. Ik vond pattern 2 het meest intuitief en het meest comfortabel.

P2: “Ik vond die op de knie meer intuitief omdat dat het gewricht is dat je beweegt en je onderbeen beweeg je niet. Die beweegt omdat andere dingen beweegt en daarom vond ik die knie logischer. Dus eerst 1 en dan 2.”

P3: “Ik vond patroon 2 het fijnst. Deze voelde ik beter. Deze ronde was echt alsof er een telefoon in mijn broekzak af ging voor mijn gevoel.”

P4: “Ik vond patroon 1 wel fijner dan patroon 2, dus degene die midden op de knie zat. Het tweede patroon was een beetje aan het kietelen onder je knie. Ik denk ook wel dat als het asfalt slechter is, dat je de feedback bijna niet meer voelt onder je knie, omdat je hele schenen dan ook mee trillen. Die op de knie is ook wat subtieler voor mijn gevoel, dan is het eerder van een : “hee iets dieper zitten”.

Legs - Trial 2: Gentle tapping motor 2 and 3

P1: “Ik denk dat ik nog steeds de tweede prettiger vond, (pattern 4) omdat deze toch wat lager zit dan de andere motor en omdat je onderbeen naar beneden moet is het wel intuitief. Dus eigenlijk hetzelfde als net. Dus 4 het meest comfortabel en intuitief en patroon 3 minder. Patroon 3 kietelt ook een beetje. Die vierde zit dan toch meer op het bot ofzo”

P2: “Ik vond patroon 4 het fijnst, die onder je knie zat. Ik vond de motor op je knie een beetje raar voelen. Onder je knie voelde wat beter. Het meest comfortabel vond ik ook de onderste. Ik vond ze allebei wel intuitief, want ze zitten bij je knie dus dan denk je wel ‘oke ik moet nu diepzitten’.”

P3: “Ik vond patroon 4 het fijnst omdat die het duidelijkst was. De tweede (patroon 3) vond ik minder. Vier voelde ik echt goed en voor drie moest ik echt focussen of ik iets voelde, dus dat vind ik minder.“

P4: “Wel grappig als dat die tapt, dat het signaal een stuk subtieler wordt. Hier voelde ik de trilling op de knie bijna niet, want voordat ik hem voelde was die al weer bijna weg. Dus deze keer was het andersom. Als je je been strekt en de motor wordt er tegenaan geduwt, dan dacht ik, ohja hij zit er wel. Nu was de tweede dus wel beter dan de eerste.

Legs - Trial 3: Directional patterns + follow me

P1: “Ik vond de follow me het minst intuitief. De middelste viel een beetje weg en dan gaat het een beetje over in een trilling. Ik vond hem niet perse het minst comfortabel, maar was een beetje medium. Opzich voelde het wel prettig, maar het voelde meer als een trilling. Patroon 6 vond ik het minst prettig.

Het voelde best wel als een harde trilling en die onderste maakte het dan af ofzo. Dat vond ik minder prettig. Die was opzich wel redelijk intuitief. Patroon 5 vond ik het prettigs, ook omdat die bovenaan begint en dan naar beneden duwt. Dat trilt wat meer op je bovenbeen."

P2: "Ik vond het soweiso intuitief dat ze alle drie van boven naar beneden gaan, want dat is ook de richting dat je heen gaat. Ik vond dan patroon 7 het meest intuitief, omdat dat het grootste bereik heeft, met eerst de bovenste en dan de onderste. Daarna patroon 6 en daarna 5. Ik weet niet zo goed waarom patroon 6 beter is dan 5, maar misschien omdat de onderste wat meer naar de grond is. Van je knie naar beneden is meer naar beneden dan van je bovenbeen naar je knie. "

P3: "Ik voelde niet super veel, ik voelde vooral bij de afzet wat. Ik voelde vooral de middelste. Het was alsof iemand een beetje op je knieën duwt. Ik voelde af en toe wel iets trillen en sommige waren iets intenser dan andere, maar ik voelde ze niet zo goed trillen en ik wist ook niet zo goed wat ik er mee moest. Misschien ook omdat ik niet wist wat het was, dat ik niet wist wat ik er mee moest doen. Ik denk dat de trilling iets aanweziger moet zijn of meer moet opvallen."

As participant three did not feel the patterns very well, it was decided to do the trial over, so that the test person could feel the patterns again.

P3: "Ik vond er geen sterk verschil tussen de patronen. Maar ik vond patroon 7 en 6 het beste, waarbij 7 het beste is en 5 iets minder. Wat mij opviel is dat je ze vooral voelt als je niet veel druk op de knie hebt, dus tijdens de afzet. Maar op dat punt kan je al niet meer dieper met de knie want dan ben je aan het afzetten. Ik vind intuitiefheid belangrijker dan comfort, maar ik vind 6 comfortabeler, want die voel je net iets minder dan 7. Met comfortabelheid gaat het er dan om dat je zo min mogelijk voelt voor mij.

P4: "Ik vond patroon 5, van boven naar beneden het fijnst. Het voelde het minst verwarrend. Het voelt een beetje afleidend van wat gebeurd er nou, wat is de volgorde. Het was best wel druk in mijn hoofd. En dan die vijfde was, je voelt hem gaan, je weet wat de volgorde is, dus hij leid niet zo af. Ik vond 6 het minst comfortabel, want op de een of andere manier voelde het alsof die heel hard trilde onder mijn knie. Daar lag in een keer heel erg de focus op. Kietelde ook. De laatste voelde een beetje all over de place, maar niet echt vervelend. Vijf is denk ik het meest intuitief ook. 6 en 7 is moeilijk, ik vond ze allebei een beetje afleiden van wat de trilling betekende en deden.

Legs - Ranking all patterns

P1: "Ik vond vijf denk ik wel het prettigst, omdat de motor toch wat hoger zit dan bij de andere. Ik vond de single pulse ook prettiger dan degene die snel achter elkaar gaan. Het is toch wat meer monotoon vergeleken met de gentle tapping. Want dan heb je feedback en daarna weer rust en dan weer feedback etc. Ik vond dat ook prettiger dan twee motoren. Bij 5 vond ik de plek het prettigst en dat vond ik belangrijker dan hoe vaak ze trillen. Dan vond ik daarna patroon 2 en daarna 1. Eigenlijk zou motor 1 single pulse helemaal ideaal vinden. De andere vond ik allemaal redelijk gelijk."

Participant 1 felt patterns 4 and 6 again to be able to make a better choice between the patterns.

P1: "Ik vond de directional patterns wel fijner dan de gentle tapping. En 7 vond ik wel comfortabeler dan de rest maar minder intutief. En vier is prettiger dan drie.

P2: "Ik vond 1 het meest intuïtief. Die was gewoon kort en duidelijk. Die andere duren wat langer. Het was gewoon zo van: "Let op nu diepzitten". Bij de andere zat er wat meer tijd tussen. Een pulse is opzich wel genoeg als het gewoon duidelijk en hard is. Daarna vond ik die na elkaar intuitief, omdat dat met de beweging mee gaat. Daarna vond ik 4 intuitief, ik weet niet waarom maar zo voelde ik dat. Voor comfort maakt het allemaal niet zo erg uit, want het zit niet in de weg ofzo. Comfortabelheid wordt denk ik beïnvloed door of de trilling intuïtief is, omdat er niets in de weg zit of erg oncomfortabel is.

P3: "Ik vond patroon 2 het chillst en daarna patroon 4. Ik vond patroon 4 en 2 het fijnst want die voelde ik het meest en het makkelijkst van allemaal. Ik had het ook chill gevonden als motor 1 en 3 werden gecombineerd omdat je die het beste voelde. Die op je knieschijf voel je nauwelijks namelijk. Het liefst 1 en 3 tegelijk die even trillen zodat je tijd hebt om het even te voelen. Ik ben geen fan van de motor op je knie omdat je knieschijf niet zo gevoelig is, dus dat voel je gewoon niet zo goed.

P4: “Ik denk dat vijf het meest comfortabel was. Het voelde gewoon het meest gestructureerd. Daarna de enkele lange pulse. Die is lang genoeg om los te staan van de rest, maar niet subtiel of heel erg intensief. Degene op de midden van de knie. Die daaronder leidde wel een beetje af. Het tappen zelf was daarna wel beter en als laatste 7 en 6. Ik denk dat dit ook aardig gelijk is aan het intuitief. Ik zou wel 7 en 6 omdraaien met 5 en 4, omdat met 7 en 6 de hele knie gestimuleerd wordt en bij 5 en 4 is dat niet het geval.

Back - Trial 1: Single pulse and gentle tapping

P1: “Ik vond patroon 2 prettiger, dat duwt wat meer naar beneden, terwijl de andere meer een reminder is. Dat zou ook kunnen werken, maar patroon 2 duwde wat meer naar beneden, dus die vond ik wat intuïtiever. Het is een wat constantere tril en daardoor vond ik het ook comfortabeler.”

P2: “Ik vond niet dat er veel verschil zat tussen de twee, maar de eerste (patroon 1) voelde je wat beter. Ik denk dat die misschien net op een bot zat en die ander net niet, dus dat hij meer door trilde. Kwa locatie maakt het niet echt uit. Dus patroon 1 vond ik beter. Ik denk dat je op je rug wat minder gevoelig bent misschien.

P3: “Patroon 2 was okayish, patroon 1 was best wel duidelijk, gewoon omdat die de hele tijd afging zegmaar. Dit is ook de eerste waarbij ik comfortabel anders vind dan intuitief. Bij de andere waren ze allemaal erg passief, terwijl patroon 1 de hele tijd afging, alsof het een soort alarm is. Als ik als trainer zelf een patroon kon kiezen en iemand zit echt niet goed diep, dan zou ik deze gebruiken. Gewoon puur omdat deze echt constant afgaat”.

P4: “Ik vond de tweede wel chiller. De eerste deed mijn denken aan mijn telefoon die in mijn zak zit. Met skeeleren heb je vaak een jasje aan met je telefoon erin. Dus het meest comfortabel vond ik ook wel twee, omdat die wat subtieler was dan de eerste. Op de rug is het veel algemener, dan ga je niet alleen letten op een been dieper maar dan op allebei de benen dieper. Omdat de motor wat hoger zit op de rug, denk je ook wel eraan dat je je rug boel moet maken.

Back - Trial 2: Direction patterns up

P1: “Ik vond deze allebei wel heftig. Veel trillingen. Van de eerste schrok (patroon 3) ik een beetje, daardoor vond ik de tweede (patroon 4) prettiger. Ik vond ze allebei niet super. Ik vond de eerste wel intuitiever, want dat heb ik ook tijdens het schaatsen van: ohja ik moet een bolle rug maken, en dat is wel wat die eerste doet, maar ik vond hem wel minder comfortabel ”

P2: “Ik vond nummer 4 het fijnst. Vier was meer intuitief en drie wat minder. Naar mijn idee ging 4 meer geleidelijk dan 3 en het ging wat soepeler waardoor het ook comfortabeler was.

P3: “Ik vond patroon 4 fijner. Ik voelde hem gewoon beter dan de patroon 3. Van patroon 4 ging ik ook het meest diepzitten.”

P4: “Ik vond ze best wel gelijkmatig aan elkaar. Ik vond patroon 4 iets harder naar mijn idee, die was iets aanweziger. Dat je er twee hebt, maakt het wel heel anders dan 1 hardere trillingen waarbij je aan je telefoon denkt. Dat is hier heel anders omdat het een heel ander gevoel is. Kwa comfortabelheid vond ik patroon 3 chiller. Je voelde hem chiller, maar hij is niet hard aanwezig. Maar ik vond 4 intuitiever, want het was meer corrigerend om een bolle rug te maken.”

Back - Trial 3: Directional patterns down

P1: “Ik vond deze een stuk prettiger dan de vorige sessies. Bij deze dacht ik wel, oh dit is prettig. Bij die eerste (patroon 5) had ik gelijk het gevoel van: “dit is het!”. Dus die vond ik het meest intuitief en comfortabel en ook prettiger dan de vorige die ik gevoelt heb.

P2: “Ik vond patroon 5 intuïtiever dan patroon 6. Patroon 5 zat meer boven in de rug en als je dieper moet zitten moet je gewoon omlaag, dus dan vond ik de trilling boven in de rug wel fijn. Dus vijf het meest intuitief en zes minder. Ik vond ze allebei prima kwa comfortabelheid, want het zit niet in de weg ofzo.

P3: "Ik vond patroon 5 fijner. Ik voelde patroon 6 niet zo goed en patroon 5 voelde ik wel heel goed. Ik weet niet zo goed hoe ik dat moet uitleggen, ik voelde het gewoon beter."

P4: "Ik vond patroon 5 fijner. Die ging wat meer naar beneden. Ik denk dat dat veel meer helpt dan de tweede, die zit wat lager naar mijn idee. De tweede voel je niet zo heel erg goed. Die eerste is veel beter voelbaar voor mijn idee."

Back - Trial 4: Follow me patterns

P1: "Ik vond patroon 7 het prettigst omdat ze best wel vergelijkbaar waren. Ik vond nummer 8 ook wel prettig, maar ik vond intuitief 7 iets prettiger, dan de achtste."

P2: "Ik vond patroon 8 fijner, omdat die omlaag ging en als je je rug boller doet, dan gaat die omlaag en niet omhoog. Ik vind het allebei even comfortabel. "

P3: "Ik vond dit veel duidelijker dan de knieën, dit is echt meer alsof er iemand gaat duwen. Tussen de twee patronen heb ik niet heel veel verschil gevoeld. Ik denk dat ik patroon 8 net iets duidelijker vond, net iets meer alsof ik dieper moest zitten."

P4: "Ik vond ze best wel gelijk kwa comfortabelheid. Ik vond het meest intuitief van beneden naar boven. Want zo vertel je ook hoe je een bolle rug maakt, dat het vanuit onderin de rug komt. Dat maakt dit veel intuitiever dan andersom. Als de trilling naar beneden gaat, denk je dat je omhoog moet gaan met je rug. Ze zijn beide comfortabel.

Back - Ranking all patterns

P1: "Ik vond 5 en 6 het prettigst. Daar had ik gelijk zoiets van: Ohja, ja dit is het. 7 en 8 waren heel vergelijkbaar vond ik. Daar kon ik niet echt zeggen dat ik de een beter vond dan de ander, maar die vond ik daarna het prettigst. Daarna de eerste en de tweede en als laatste de derde en vierde. De derde en vierde vond ik echt het minst prettig. Twee was iets gelijkmatig dan 1, dus dat voelde iets lekkerder. 1 t/m 4 vind ik wel minder natuurlijk dan de laatste twee blokken. 3 is wel meer hoe je het in je hoofd ook hebt, maar dat is dan iets meer een schrikreactie. Ik had ook het idee dat er bij 3 wat meer tijd tussen de trillingen zat bij 4.

P2: "Het meest intuitief vond ik een pulse. Dus geen patroon. Als je aan het skeeleren bent, vind ik het wel chill als er gewoon een ding trilt en niet meerdere dingen. Daarna vond ik 8, degene die naar beneden gaan wel chill. Die omhoog ging vond ik niet chill, dus niet intuitief. Ik vond naar beneden beter dan omhoog voor de directional patterns. Ik vond ze allemaal prima kwa comfortabelheid, dus dan doe ik het hetzelfde als voor de intuitiefheid."

P3: "Ik vind van de slechtere moeilijk, want ik vind ze allemaal niet heel goed. Dat zijn 7, 6 en 3. Ik heb vooral gekeken naar wat ik chill vond. Ik denk dat ik 4 beter vond dan 5. Degene die ik het minst fijn vond is degene die ik bijna niet voelde. Ik dacht op een gegeven moment ook alsof die uit stond. Ik vind 1 niet heel comfortabel, dat wil ik gewoon geen hele training voelen."

P4: "Ik denk dat het meest comfortabel en intuitief 7 en 8 zijn omdat de hele rug geprikkeld wordt om bol te gaan. Ik weet niet of 8 beter is dan 5 en 6. De patronen zijn net anders, doordat ze meerdere motoren hadden. Dus ik denk 7, 5, 6 en dan 8. Helemaal aan het einde vond ik de enkele pulse, waarbij de lange pulse een beetje afleiden omdat je niet wist of het nou een telefoon was of niet. Ik denk dat 5 en 6 comfortabeler zijn dan 7. Nee, 7 is toch het meest comfortabel omdat hij toch wel voorspel is en intuitief. Misschien dat je 3 en 4 omdraait, omdat 4 toch wel iets aanweziger is.

Transcription interview

Zou je nog wat veranderen aan de feedback?
P1: “Ik vond op de knie iets natuurlijker dan op de rug. Op de knie heb je al beschermers, dus dat ben je al gewend en voelt dan toch iets natuurlijker. Ik denk dat ik de simpele patronen wat fijner vond dan complexe patronen omdat simpele patronen wat meer rust geven tijdens het skeeleren, want je moet toch weer op de patronen letten tijdens het skeeleren. De rustige patronen zijn wat meer in het cadans van het skeeleren.

P2: “Ik vond het wel goed. Door de feedback denk je meer na wat je doet. Ik zou niets aan de feedback veranderen. Als ik aan het skeeleren ben, denk ik niet echt na en door de trilling krijg je wel een reminder om dieper te zitten of je rug boller te maken. En als je dat voelt ga je dat wel doen. “

P3: “Bij mijn knieën voel ik het niet erg. Je voelt de feedback vooral tijdens de afzet, terwijl het dan niet heel erg nodig is. Misschien kan je de trilling op een plaatje zetten, zodat je de trilling beter vond. Ik vond het wel fijn als die bovenin af gaat. Ik vind de pulsjes wel beter dan het tappen, want het tappen voel je nauwelijks bij de knie, dus dan zijn pulsen beter. “

P4: “Ik vind de feedback wel grappig. Wel interessant dat je trillingen voor dit doeleind gebruikt. Ik ben trillingen gewend als heads-up van: hier heb je meer informatie. Nu weet je het antwoord als maar is de trillingen om ergens op te letten. Nu komt het meer vanuit jezelf en hoef je niet op te letten wat de trilling betekent, dat is wel grappig. Ik vond de rug wel uniformer voelen dan 1 knie. Maar twee knieën is misschien erg veel als je beide geeft. Als je feedback voelde als je op je standbeen stond, dan is dat wel intuitief. Als dat tijdens de afzet is, is dat niet logisch. Dus ik denk dat je hem per knie moet laten voelen als je op de knie staat, zodat je het om en om voelt, maar het kan zijn dat dat erg druk voelt. Ik weet ook niet of je het elke slag wilt voelen of af en toe na 5 minuten ofzo voor een paar slagen. Als je dit non-stop voelt tijdens een training, dan ben je er wel klaar mee. Want het kan ook vermoeide benen zijn of dat je er klaar mee bent.“

Hoe vaak zou je feedback willen krijgen?
P1: “Het liefst zou ik feedback krijgen als je het fout doet en dan voor meerdere slagen, zodat je echt even denkt “nu dieper zitten”, dus iets van 4 slagen ofzo. Want met een slag denk je “oh dieper zitten” en dan ga je weer omhoog. Als je het elke keer hebt, dan raak je er aan gewend en doe je misschien niets meer met de feedback.

P2: “Vooral als je het fout doet, en als je het heel lang goed hebt gedaan dat je een ander patroon krijgt die zegt dat je het goed doet, zodat je wel weet of je het fout of goed doet. Zolang je het fout doet zou ik het patroon willen voelen, ik denk dat dat het meest motiverend is, want dan weet je ook van ‘oh deze slag was fout en deze slag was goed’.

P3: “Je zou in principe constant feedback kunnen krijgen. Ik denk dat dat voor de training het beste is, maar je moet het niet alle trainingen hebben. Je moet het wel maar voor een bepaalde periode doen, bijvoorbeeld vijf minuten. Niet een hele training. Ik denk dat als het de hele training werkt, dat het dan goed is. Maar ik kan mij ook voorstellen dat je went aan de pulsen. Ik zou het sowieso wel voor een oefening doen, zodat je hem wel even draagt, maar het moet niet in combinatie met een techniek oefening. Eerder met een steigerung of een piramide oefening.“

P4: “Ik denk dat om de zoveel minuten feedback echt wel beter is dan non-stop feedback. Als je binnen een trainingsblok verslapt, moet je wel feedback krijgen. Maar als je het goed doet en je krijgt feedback, is het wel frustrerend. Dus eerder corrigerend en niet non-stop. Eigenlijk moet het een beetje een trainer zien die af en toe schreeuwt dat je dieper moet zitten. Als een trainer altijd schreeuwt is het ook irritant.

After the recording stopped, participant 4 also mentioned that advanced inline skaters often do not wear protection. This means that some the sensors should be able to be taped to the knee or be attached to a knee band or something to attach the motor when no knee guards are worn.

Wat vond je van de lengte van de patronen?
P2: “Dat was goed, want het zit in een slag. Als het binnen een slag valt is het goed, als het langer is dan 1 slag dan is het te lang. Misschien als je sneller skeelert dat het te lang is, maar voor normaal skeeleren is het goed.”

P4: “De enkele trillingen op de knieën werd wel voelbaarder omdat het lang was, omdat je het minder snel voelt. Op de rug was een lange trilling bijna afleidend omdat het dan lijkt op een telefoon die afgaat. Dus op de rug kan die wat korter. Maar het patroon op de rug voelde wel goed, wel aardig aan de slag van het skeeleren gekoppeld. Het moet ook niet echt sneller. Dit was wel aardig gelijk aan het tempo van de slag, daardoor voelt het wel natuurlijk.

Appendix F

Tables evaluation test

Table F.1: The average knee angle during the different trials with different types of feedback. The data is corrected for fatigue.

Participant	**Leg**	**No Feedback**	**Knees**	**Back**	**Both**	**No Feedback 2**
Participant 1	L	132,23	132,07	132,58	132,12	131,75
	R	133,30	132,89	132,51	133,15	133,24
Participant 2	L	111,59	111,33	116,64	108,41	109,24
	R	109,70	109,22	117,21	112,22	119,67
Participant 4	L	114,83	115,51	115,26	113,20	123,02
	R	110,71	109,58	108,01	108,96	108,97
Participant 5	L	121,53	120,35	124,23	119,65	127,47
	R	108,15	107,55	110,32	107,49	114,39
Participant 6	L	112,19	113,81	113,07	108,41	111,91
	R	98,24	99,71	96,80	97,57	97,98
Participant 7	L	104,89	104,44	107,51	104,36	111,89
	R	107,39	108,51	114,75	109,26	117,89
Participant 8	L	119,56	118,01	121,34	120,02	128,05
	R	110,67	110,89	109,74	110,29	116,60
Participant 9	L	101,79	96,70	99,73	99,48	102,24
	R	104,06	96,84	97,23	100,26	94,55
Participant 10	L	135,00	133,52	135,05	134,38	135,01
	R	125,21	122,00	126,16	123,44	125,20
Participant 11	L	131,72	129,76	135,91	133,12	132,95
	R	125,00	125,50	128,30	126,64	128,06
Participant 12	L	124,06	117,33	124,36	117,13	133,25
	R	119,87	113,99	117,70	112,17	127,00
Participant 13	L	130,43	129,47	132,28	127,64	128,60
	R	117,67	115,40	115,76	117,90	112,42
Participant 15	L	103,00	106,15	105,01	104,86	107,60
	R	107,56	108,23	108,79	107,76	112,42
Participant 17	L	130,95	123,56	133,84	126,16	135,23
	R	125,94	118,66	123,14	120,61	119,55
Participant 18	L	129,34	126,38	125,19	129,75	136,51
	R	130,88	132,03	131,36	130,72	128,29

Appendix G

Interview evaluation tests

Wat vind je van het apparaat?
P1: “Ik vond het wel leuk dat er feedback was en ik vond het ook goede feedback. Het was duidelijk wat je fout deed en wat je moest doen. Ik vond het ook leuk dat er positieve feedback was. Als je het goed doet krijg je een schouderklopje. Zo denk je niet als je goed doet: “oh ik ontvang niets, is hij kapot ofzo”. De positieve feedback laat zien dat alles nog werkt en het is gewoon leuk want dan weet je dat het je goed aan het doen bent. De feedback is ook nuttig. Soms ben je aan het skeeleren zonder na te denken en dan voel je een trilling en dan denk je “ohja, ik moet diepzitten”.

P2: “Ik vond het wel helder. Ik vroeg mij wel af en toe af wat de sample frequentie is. Doe ik het nou langere tijd niet goed of was het een afzet die ik niet goed deed. De feedback dwingt je wel om dieper te zitten en je rug boller te maken.”

P3: “Ik vond de feedback wel fijn. Ik had wel het gevoel dat het echt iets deed. Het was ook wel op de punten waarop ik het verwachtte, dus dat was wel fijn. Ik vond het schouderklopje ook fijn, dat is wel heel positief dan weet je dat je het goed doet. Je merkte ook wel dat als ik feedback had gekregen dat ik dieper ging zitten en dan kreeg ik de feedback ook even niet, dus dan wist ik dat ik het goed deed.”

P4: “De knieeën vond ik een beetje onwennig. Ik kreeg er “huuuh vibes” van. Door de plek onder mijn knie vond ik net triggerde een reactie van eng vies, een beetje alsof een dokter met zo een hamertje op je knie gaat slaan. Ik vond wel dat de motor voor m’n gevoel soms wel erg hard trilde.”

P5: “Ik vond die van de rug een beetje nutteloos want die gaf alleen maar schouderklopjes. Voor de knieën in de eerste sessie dacht ik “ohja ja, reminder dieper zitten” maar bij de laatste sessie was het wel een beetje van: ja dat wil helemaal niet. Ik zit al zo diep als dat comfortabel is voor 4 minuten. Dus toen was hij wat vaker aan het trillen. Maar opzich als je het vaker gaat gebruiken dan moet je de hoek wel een keer aanpassen omdat iemand dan heel veel voelt of heel weinig. Aan het begin dacht ik wel “inzakken” als die aan het trillen was. Toen ik geen feedback kreeg was ik weer met alles bezig behalve de kniehoek en de bolle rug. Maar meer met andere technische dingen.”

P6: “Ik denk dat het voor de knieën echt wel werkte voor mijn gevoel. Als ik omhoog kwam in de bocht, kreeg ik wel feedback. Voor de rug heb ik eigenlijk niets gevoeld dus ik weet niet dat het werkte. Bij de knieeën voel je een paar tikjes en dan weet je dat je dieper moet zitten.”

P7: “Ik vond het best wel nice. Je hoeft er niet echt op te letten of je diepzit of niet, want dat doet het apparaat voor je. Ik kon letten op andere dingen en als ik niet diepzat, dan kreeg ik feedback.”

P8: “Ik vond het wel echt chill. Ik vond het fijn dat het werkte. Je merkte tijdens het skeeleren niet dat je het om hebt, behalve de draadjes die bij je been hangen, daarbij denk je ‘gaat dat wel goed’. Verder merk je er niets van, maar als je zo een trilling voelt bij je knie denk je wel van: ‘Oh ik zit niet diep genoeg’, dan ga je wel automatisch dieper zitten. Maar als je de feedback meerdere keren krijgt en daarna even niets en dan weer meerdere keren feedback. Maar als je dat een paar keer krijgt is het niet zo motiverend. Maar als je het goed doet, is het wel heel motiverend en is dat schouderklopje wel fijn. Ik vond het wel leuk. ”

P9: “Ik vond het wel gewoon goed. Het kan je helpen met techniek. Je had er geen last van tijdens het skeeleren ”

P10: “Ja vooral die knieën was wel chill. Ik had er wel echt wat aan, dat je goed kan voelen wanneer je wel goed zit en wanneer niet. Ik herkende ook wel van: ohja, ik moet wel zo diep zitten’, dus dit was wel een reminder van: ohja even beter je best doen.”

P11: “Best wel lachen, best wel leuk. Ik vond het niet te vaak en niet vervelend. Het is een soort reminder dat je dieper moet zitten. En dan merk je zelf ook wel van: “ja ik was een beetje aan het verslappen.” Het is wel nice.” P12: “Ik vond het wel prima. Ik had er geen last van verder. En de trillingen die hielpen je er wel aan herinneren dat je goed moest gaan zitten.”

P13: “Het was wel grappig om direct feedback te hebben om hoe je zit. Maar als je niet dieper kan omdat je heel moe bent, en het ding blijft zeggen dat je moe bent, dan is het wel frustrerend.”

P14: “Leuk, aan het begin vond ik het een beetje irritant. Dan zit je niet goed, dan krijg je de hele tijd trillingen en dan denk je: “Ja ik weet het, maar ik ben gewoon moe.” Maar als het goed gaat dan heb je wel een positieve vibe dat het goed gaat. Dan geeft het extra motivatie om wel goed in de houding te blijven zitten.”

P15: “Ik vond het eigenlijk wel een mooi ding. Ik had er geen last van tijdens het skeeleren. Ik had niet door dat ik hem om had. Ik vond de feedback wel fijn. In het begin kreeg ik steeds schouderklopjes, terwijl mijn techniek misschien niet helemaal goed was. Aan het einde, als ik hoger ging zitten kreeg ik wel goede feedback. Mijn rug bol maken ging wel goed, daar kreeg ik alleen goede feedback. Ik had wel soms het idee dat ik technisch slordig reed, maar dan kreeg ik wel feedback dat het goed was. Maar hij keek natuurlijk niet naar alle techniek. ”

P16: “Los van dat de draadjes soms los komen, vind ik het opzich wel interessant. Het maakt je wel bewuster waar je op aan het letten bent. Het is best intensief dus op een gegeven moment dwalen je gedachten af. Als je constant een schokje krijgt is het wel een reminder dat je moet letten op je houding.”
P17: “Ja leuk”

P18: “Handig en goed. Duidelijk, hij gaf duidelijke signalen.”.

Heb je het idee dat je houding hierdoor verbeterd wordt?
P1: “Ja wel dat je er beter op gaat letten, dus dat je wat meer constant goed zit ipv even niet en even wel.”

P2: “Ja opzich wel. Ik ging wel meer diepzitten, dat is wel de houding verbeteren. Mijn rug deed ik meestal wel goed, maar soms ook niet.”

P3: “Ja, ik merkte ook dat de laatste 4 minuten dat het anders was dan daarvoor als je wel feedback krijgt. Als ik gewoon rondjes rijdt, dan let ik niet op mijn houding maar met de feedback lette ik er wel op. Maar je merkte wel dat het iets deed.”

P4: “Ik ging vooral focussen op specifiek de sensor blij maken en niet perse een goede houding hebben. Je kan je knieën een negentig graden hoek maken en je rug bol. Dan ging ik dat doet, maar dan keek ik niet naar hoe mijn kniehoek was ten opzichte van de grond. Dus dan denk ik dat het een beetje verbeterde, maar soms focuste ik op de sensor blij maken maar niet mijn houding verbeteren.”

P5: “Ja iets, iets meer kniehoek. Maar ik dacht, m’n knieën meer naar voren duwen gaat niet, dus dan mijn kont iets naar beneden. Maar eigenlijk toch niet. Dus nee. Uiteindelijk ga je toch naar een hoek toe die voor langere tijd chill skeelert, in plaats van de hoek die het apparaat aangeeft. maar ik denk wel dat het heel goed is voor beginners. Want als je al 8 jaar skeelert en veel begeleiding erin hebt gehad, dan weet je wel wat ongeveer goed is en dan moet je het toch op gevoel doen. Voor langere duurritten als je omhoog komt als je de vermoeiing hard in gaat, dan kan de feedback wel nuttig zijn. Maar voor vier rondjes toeren is het niet echt nodig.”

P6: “Ja ik denk dat mijn houding wel beter was door de feedback.”

P7: “Ja opzich wel, als je moe wordt en je komt net even omhoog dan dan voel je een trilling en dan denk je ‘ohja, weer even diepzitten’.”

P8: “Ik denk het aan de ene kant wel, maar aan de andere kant niet. Ik had soms niet het idee dat ik dieper zat en dan gaf die wel positieve feedback. Ik denk wel een beetje, maar je moet wel een bepaald niveau hebben voordat het effect heeft. Als je nog veel moet nadenken hoe je skeelert, dan kan het je uit balans brengen. En dan heeft het geen effect op je houding. Hij meet ook niet hoe ver voorover of achterover je gaat zitten, dus dan ga je dieper zitten door meer voorop te zitten. Dan is je kniehoek lager maar je algemene houding niet. ”

P10: “Ja, het wordt ook een beetje een soort spel dat je gaat zoeken naar de juiste houding. Je doet dan extra je best om dat ding te verslaan, dus als je dan feedback krijgt, denk je, nu moet ik wel in de houding zitten. ”

P11: “Niet perse verbeterde, maar wel consistent bleef. Dus dat je niet verslapt.”

P12: “Ja, want als je zo een trilling voelt ga je er wel over nadenken en denk je wel, nu moet ik beter in mijn houding zitten.”

P13: “Het is wel een extra motivator om dieper te gaan zitten en je word er wel de hele tijd aan herinnert. Maar ik weet het ook wel van training. Ik weet niet of het mij heel erg helpt.”

P14: “Nee, want ik was gewoon moe.”

P15: “Ja ik denk het wel. Ik denk wel dat ik dieper ging zitten.”

P16: “Ik weet niet of mijn houding er beter van werd, maar ik ging wel beter opletten op mijn kniehoeken.”

P17: “Ja want als je niet diep genoeg zat, werd je attent gemaakt op het feit dat je niet diep genoeg zit door de trilling op je knieen. Dus dan ga je automatisch diep zitten.

P18: “Ja, als je een signaal krijgt denk je wel, ik moet dieper zitten”.

Zou je het gebruiken tijdens het skeeleren?

P1: “Ja, ik weet niet of ik het iedere keer zou gebruiken, maar wel een keer per week ofzo als je meerdere keren per week traint”.

P2: “Ik denk als je echt een training hebt waar de training focust op diepzitten of een bolle rug, dan is het wel handig. Ik vond de bolle rug minder helder want daar ben ik nooit mee bezig. In zo een situatie is het wel nuttig.”

P3: “Niet altijd, maar als je het drie keer in het seizoen zou doen of als je echt een training hebt waarbij je focust op de houding, dat het dan heel fijn kan zijn. Ik zou het niet continue prettig vinden omdat je ook op andere dingen wilt letten of dat je gewoon lekker wilt skeeleren. Dan hoeft het niet, maar als het gefocust is op houding dan zou ik het gebruiken.”

P4: “Ik zou de motoren voor de knieen niet gebruiken, want ik vond ze best wel naar. Die voor de rug zou ik wel gebruiken omdat dat wel iets is waar ik moeite mee heb. Vaak heb ik dat niet door totdat ik weer bij de trainer komt en er een opmerking over krijg. Dan is instant feedback wel fijn, want als je bezig bent vergeet je het gewoon.”

P5: “Ik zou het voor nu en dan is een keer bij een training gebruiken. Maar ik denk dat je er nog steeds een trainer bij moet hebben. Als je zelf zou skeeleren zou ik het niet doen, want dan ga je lekker toeren.”

P6: “Ik zou het niet elke keer gebruiken denk ik. Dat is omdat het moeite is om het aan te trekken en omdat hij wel groot is. Ik zou het wel gebruiken als het compacter was en wat meer geïntegreerd. Maar ik zou het wel eerder gebruiken met schaatsen dan met skeeleren eigenlijk, want met skeeleren zit je toch wat hoger nog.”

P7: “Ja ik vond het wel nice”.

P8: “Tijdens een training wel. Maar niet tijdens een hele training. Bijvoorbeeld bij het inrijden. Als je een intensief interval training hebt weet je toch wel dat je aan het einde minder diep zit, dus als je dan helemaal kapot bent en dan feedback krijgt dat je niet diep zit, dan is het wel vervelend. Maar ik zou het wel willen gebruiken. ” P9: “Ja”

P10: “Ik vind het skeeleren vooral voor de leuk en als ik er wat van opsteek is het mooi. Voor een keer zou ik het wel leuk vinden zodat je je een keer bewust bent van je houding, maar ik denk dat het vooral veel baat heeft bij wedstrijdsporters om echt te hameren op de juiste houding. Dus dat je het zo vaak triggert dat je bijna niet meer anders kan. Maar ik wil gewoon toeren.”

P11: “Misschien, als er iets minder draadjes zijn, zou ik het wel gebruiken. Niet altijd maar een keer tijdens een duurtraining ofzo. Want dan weet je dat je gaat verslappen na een paar kilometer dus dan is het wel nice om te hebben.”

P12: “Ja, ik had er verder geen last van en het helpt je er elke keer aan herinneren dat je beter moest skeeleren dus ja. Het is alleen een gedoe met aandoen elke keer.”

P13: “Ik denk dat het in het begin stadia van mijn carriere heel handig was geweest. Als je echt de houding nog aangeleerd moet krijgen. Nu weet ik het ook wel en als ik het kan doe ik het ook wel, maar als ik niet meer kan, dan doe ik het ook niet. Ik had wel een paar keer dat ik dacht dat ik een bolle rug had, maar dan ging hij trillen en toen dacht ik wel, ohja daar heb je misschien gelijk in. Dus in dat opzich is het misschien wel handig. ”

P14: “Ja, ik denk het wel. Je hebt toch vaker de feedback die je mist als je een trainer hebt voor 15 of 20 personen. Nu heb je direct feedback van: even diepzitten. ”

P15: “Weet ik eigenlijk niet. Ik denk het wel. Ik denk dat het wel meerwaarde heeft, maar ik doe vooral kort werk op de skeelers en ik weet niet of het dan veel nut heeft. Maar voor duur training zou ik het wel gebruiken.”

P16: “Ik zou het in het geven van trainingen wel gebruiken als het compacter is, als het makkelijker aan te trekken is. Ik denk dat het een goede prikkel kan zijn. Dus dan zou ik het wel gebruiken”

P17: “Nee omdat het aan- en uittrekken teveel werk is. En ik denk dat je na twee of drie keer wel weet waar de fouten zitten.”

P18: “Nee, ik ben niet zo serieus met skeeleren, dus ik vind het niet zo belangrijk dat ik netjes kan skeeleren.”

Wat vond je van de motor op je knie?
P2: “Ik merkte er eigenlijk niets van, behalve als die trilde. En als die trilde dacht ik wel dat ik dieper moest zitten. Vaak deed die links, rechts en dan allebei en dan dacht ik wel: “Hoo rustig joh, ik ga al dingen doen”. Het was net op het randje, als die nog een keer trilde werd ik er gek van.”

P3: “Ik vond de motor op de knie niet onprettig. Het trilde ook niet te hard of te zacht. Het was helemaal goed”.

P4: “De knieeën vond ik een beetje onwennig. Ik kreeg er “huuuh vibes” van. Door de plek onder mijn knie vond ik net triggerde een reactie van eng vies, een beetje alsof een dokter met zo een hamertje op je knie gaat slaan. Ik vond wel dat de motor voor m’n gevoel soms wel erg hard trilde.”

P5: “Had ik geen last van. Ik had alleen last van het klittenbandje op de bovenbeen als ik ging overstappen.”

P6: “Ik had er geen last van.”

P7: “Ik vond het niet storend ofzo. Aan het begin dacht ik wel een beetje, oh het kietelt maar daarna vond ik het best wel oke”

P8: “ Ik vond het wel prima. Ze zijn wel intens, ik schrok er wel elke keer van. Maar je wilt wel de feedback hebben, dus het is wel fijn. Misschien zou ik het aan de zijkant van de bovenkant willen, maar dat is erg persoonlijk. ”

P9: “Het zat prima, alleen met die draden kwam ik soms met mijn armen tussen de draden met de armzwaai. ”

P10: “Die is wel prima. Ik weet niet of hij meerdere keren trilde of hij was heel lang, want soms dacht ik wel: “Jahaa ik weet het”. Die bij de rug en de schouder waren minder lang. Ik had ook wel het idee dat de trilling op je knie vaker was dan die op de rug. Maar de kniehoek is ook wel het belangrijkst met skeeleren voor mijn gevoel. ”

P11: “Ik had er geen last van.”

P12: “Die voelde je gewoon normaal, was niet vervelend ofzo. Was wel prima. ”

P13: “Ja prima, was duidelijk te voelen en ik had er geen last van.”

P14: “Prima, niet irritant.”

P15: “Ik vond het wel fijn. De feedback was niet vervelend. Het zat ook wel prima.”

P16: “Geen last van, prima. Hij was duidelijk te voelen.”

P17: “Ja prima, functioneert goed”.

P18: “Ook prima, gaven ook goede signalen en je had er geen last van”.

Wat vond je van de motoren op je rug / het tuigje?
P2: “De motoren op je rug vond ik subtieler en niet hinderlijk. Ik had ook geen last van het tuigje.”

P3: “Die op mijn rug heb ik niet gevoeld tijdens het skeeleren, maar het schouderklopje was wel echt als een schouderklopje”.

P5: “De buikband zou ik elastisch maken, want als je staat ging het prima maar als je inzakt zat de band strakker, maar dan moet de band weer losser waardoor de band op je rug minder strak zit.”

P6: “Zat prima, had ik ook geen last van.”

P7: “Ook geen last van eigenlijk, ze deden wat ze moesten doen. Ik vond het niet storend dat ze er zaten”

P8: “Ja vond ik ook wel prima, maar daar merkte je ook niet zoveel van omdat hij het best wel snel vind dat je het goed doet omdat het een lastige hoek is om te meten. Ik vond het wel leuk dat het er drie waren, dat het een patroontje was.”

P10: “Ik vond ze wel prima, maar ik kreeg wel heel veel schouderklopjes. Ik vond het fijn dat de motor zat op de plek waar je het goed of fout deed. Dat was met de schouderklopjes lastiger, want dan weet je niet wat je goed doet. ”

P11: “Beetje warm, maar verder wel prima. Niet vervelend, wel goed.”

P12: “Ook gewoon prima. Je voelde ze wel, maar het was niet vervelend ofzo of irritant. Het was wel duidelijk”

P13: “Ook prima, duidelijk te voelen en geen last van.”

P14: “Ik merkte er niet heel veel van. Het zat gewoon prima. ”

P15: “Ik vond het ook goed. Het zat mooi strak om het bovenlichaam heen. Het was niet aan het fladderen, alleen de draadjes af en toe maar daar had ik niet echt last van. Ik had niet het idee dat ik echt een heel ding aan had.”

P16: “Heb je ook geen last van. Ik voelde zelf de rug minder goed. Tijdens de eerste ronde voelde ik hem beter, maar misschien was ik er meer op aan het letten. Toen ik de knieeën voelde, voelde ik de knieën meer.”

P17: “Tuigje is een beetje gedoe om aan te trekken. Maar de feedback op je rug is ook wel prima, dat je een schouderklopje krijgt. Dat is lekker duidelijk. Je hebt ook maar twee dingen dus dat is lekker overzichtelijk.”

P18: “Prima, het was niet zwaar ofzo. Je voelt het niet echt.”

Wat zou je veranderen?
P1: “Ja minder kabeltjes overal, maar dat is iets voor een later design, dus ik denk het niet.”

P2: “Ik zit meer te denken als je nog een sensor doet. Dan zou ik wel graag een sensor hebben voor de heup in de bocht. En ik zou de knieën misschien minder agressief maken, maar de motoren maakte wel indruk. Ik vond het schouderklopje wel leuk.”

P3: “Het zijn nu wel veel draadjes, maar ik weet niet of dat iets is waar je iets aan kan doen. Maar het zou prettig zijn als dat allemaal geïntegreerd is of dat het onder je broek zit ipv erover. Ik vond de draadjes ook niet onprettig hoor. Ik vond het tuigje ook helemaal niet onprettig, dat merkte je helemaal niet. Dat zit helemaal goed en helemaal lekker”.

P4: “Ik zou de trillingen minder hard zetten en de plaatsing van de motoren op de knie veranderen naar bijvoorbeeld de bovenbeen. Ik denk dat dat een iets chillere en minder storende locatie is. Ik zou het apparaat ook draadloos maken en compacter. En iets doen zodat het makkelijk aan te trekken is en uit te doen. “

P5: “Cable management, zodat je minder tapejes gebruikt. Ik zou de kabels iets meer bundelen. Ik zou de trilmotoren ingieten in plaats van 3D printen, maar dat is iets teveel werktuigbouwkunde misschien. Via een telefoon en app of Garmin implementatie zou wel helemaal top zijn. Dan kan je op je scherm zien wat je goed doet of fout doen. Maar dat is doorontwikkeling voor als het conceptueel goed is. Je zou het ook kunnen uitbreiden naar meer hoeken, zoals enkelhoeken en heuphoeken. Er zit wel verschil in je hoeken tijdens en slag en tussen verschillende slagen. Dus misschien kan je er wel betere feedback opgeven als je dynamisch kalibreert.”

P6: “Ik vond dat rug feedback niet zo zinvol was voor mij, dus dan zou ik liever feedback krijgen op mijn enkel-strekking, omdat dit iets is waar ik feedback op nodig heb. Dus dat je sensoren op je enkel en teen doet om te kijken of je je voet volledig strekt, maar de knieën zou ik er wel inhouden.”.

P7: “Niet perse, ik merkte zelf weinig van de rugmotor, maar ik denk wel dat het werkt.”

P8: “Ik zou zelf de trilmotoren verplaatsen naar de zijkant van mijn bovenbeen, maar dat is puur persoonlijk. Misschien zou ik ook veranderen hoe die de bochten detecteert. Nu had ik het idee dat die nu vaak feedback gaf in de bochten en ik weet ook niet of dat altijd klopte met het gevoel. ”

P9: “Nee niet echt.”

P10: “Wat nu lastig is, is dat je niet weet of je het zelf heel goed deed of dat de sensor het niet goed pakte met de rug. Voor de knieën werkt dat beter. En misschien beter onderscheid van welk schouderklopje waarbij hoort. Het is wel chill om te weten wat goed is en wat fout is bij het schouderklopje. ”

P11: “Ja toch de manier hoe de motoren op de knie vastzitten. Misschien kan je het in de banden doen van de sensoren, dat je een trilling op de been hebt, maar dan hoef je geen kniebeschermer om of een plakkertje daar. Dus dat zou ik aanpassen.”

P12: “Nee, denk het niet. Ik zou niet weten wat.”

P13: “Het bandje om mijn knie schuurde aan de binnenkant van mijn lies, dus misschien dat dat glad kan zijn. Voor de rest was het wel prima.”

P14: “Nee, maar misschien kan je het meten en dan feedback geven als iets boven een bepaalde waarde is, in plaats van elke 30 seconden feedback geven. Als je een paar keer kijkt en het is boven een bepaalde waarde dan feedback geven. Dan heb je iets meer de stimulatie hebben van weer eronder.”

P15: “Misschien zonder bedrading als dat kan. Verder is het al best wel een klein, compact ding.”

P16: “Voornamelijk iets compacter. De draadjes op de rug zijn misschien niet handig met je bewegingen. Misschien is dat nadelig, want je wil niet dat je gaat compenseren op andere plekken als het je houding moet verbeteren. Verder kan het schouderklopje misschien iets aanweziger zijn. Maar het kan ook aan mij liggen of aan de kleding.”

P17: “Misschien een schema, dat je kan aflezen hoe lang je diep hebt gezeten en hoe de kromming van je rug is. Net zoals met schaatsen, dus dat je weet hoe hard je wanneer ging en hoe diep je zat etc. Een soort van vinksite voor je houding. En dan kan je het ook vergelijken met je snelle tijden”.

P18: “Nee, alleen het snoertje bij de knie moet wat langer.”

Heb je nog opmerkingen?
P1: “Nee eigenlijk niet. De motoren zaten ook niet in de weg, dus dat was wel fijn. Verder heb ik geen opmerkingen.”.

P3: “Nee, ik vond het wel nuttig. Ik denk dat als je er echt op kan trainen, dat het heel chill is als die het meet en steeds feedback geeft op een iets lagere kniehoek totdat je uiteindelijk in de juiste houding zit. Dat lijkt mij heel fijn.”

P4: “De draden stonden soms af en toe te strak waardoor ik in mijn bewegingen gelimiteerd worden, dat was wel naar. Als het een heel ding zou hebben wat mensen gaat gebruiken, dan zou het wel chill zijn als er een app bij komt waarbij je je data van trainingen kan vergelijken met andere trainingen enzo.”

P7: “Nee, je kan het natuurlijk met heel veel houding technische dingen doen. Dus dat je dingen toevoegt zoals achterop zitten ofzo. Dus je kan het nog heel veel uitbreiden als je wilt. “

P8: “Nee, want ik vond het ook goed dat je positieve feedback kreeg, dus dan weet je ook dat je het goed doet. Maar als je niet de positieve feedback krijgt, dan weet je niet of je het wel of niet goed doet. Dan had je een tijdje geen trilling. Als je alleen trillingen krijgt is het ook averechts. Maar als je dan niets krijgt weet je niet of je het wel of niet goed doet. ”

P9: “Nee, ik vond het wel een goed apparaat als je je techniek wilt verbeteren.”

P10: “Het is wel lastig hoe het draadje langs je heupen gaat, maar ik denk als het een professioneel apparaat is, dat dat wel op te lossen is. Dan kan die geïntegreerd worden in een broek ofzo. ”

P11: “Ik vond het schouderklopje leuk. Fijn dat je de feedback krijgt dat je weer goed gaat diep zitten en dan krijg je het schouderklopje en dan weet je dat je het goed doet. Dus best wel nice. ”

P12: “Nee, ik vond het wel leuk om te doen. Als ik het persoonlijk zou gaan gebruiken, moet het makkelijker aan te doen zijn, maar verder heb ik geen aanmerkingen.”

P13: “Misschien dat het kalibreren makkelijker kan, zodat je dat on the fly kan doen. Dat zou wel handig zijn. Verder heb ik niets. ”

P15: “Ik vind het wel een leuk onderzoek. Ik ben benieuwd wat eruit komt.”