Keeping volleyball players on their toes: a haptic feedback design

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Abstract

Feedback is essential to improve sports skills. To provide more feedback than a trainer can do, technology can be used in three modalities: vision, audio and haptics. Haptic technology can be defined as computers that interact with humans via touch. To discover the possibilities with haptic feedback on posture and movement in sport, this study aims to determine how a haptic feedback system could be designed to stimulate volleyball players to shift their weight to their forefeet. This active posture with the weight on the forefeet is an important posture in volleyball. By researching the state-of-the-art literature and existing work, designing a prototype and doing user tests, insight is gained into the design possibilities within haptic technology systems and the application of haptic feedback in volleyball. Participants in the user test were volleyball players with different levels and amount of experience. The prototype that provided vibrotactile feedback was found to provide clearly noticeable feedback. Experienced users are better able to interpret the feedback and improve their posture. The current prototype design does not stimulate an immediate upward movement of the heel, but more a notification of an incorrect posture. However, the prototype was still evaluated positively. It should be further researched whether a different design is more stimulating and how different aspects influence the experienced stimulation.

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1. Introduction

1.1. The Project

An athlete often has the goal to improve his or her skills. Feedback is essential to achieve this goal [1]. One form of feedback is augmented feedback, which can be defined as feedback provided by an external source. A trainer, coach, or fellow athlete can act as this external source. In individual sports, like running, augmented feedback is often lacking. In team sports, like volleyball, it is more common to have a trainer to guide the team. However, a team trainer is not constantly focused on an individual athlete, but on the whole team. This leads just like in individual sports to less guidance than might be helpful or needed. An example in volleyball could be that the trainer teaches the athlete to move both arms up when jumping to attack instead of one arm. It would be best if the athlete would receive feedback every time the action is performed to learn the fastest. However, the trainer also has to guide other players and therefore cannot constantly focus on one player. It will take more time for the player to improve the movement. Therefore, it is interesting to explore the possibilities of giving feedback in an alternative way.

Technology could be an outcome since it can be designed to act as an external source of feedback or to assist as an additional source of feedback. In situations in which feedback is fully missing, technology can be designed to provide the feedback. In situations in which feedback is already present, but focus on individuals or details is lacking, feedback provided by technology can be used to amplify the feedback provided by a trainer or coach. Besides, technology can be very accurate in sensing and providing feedback. Therefore, it gives an advantage over a human feedback source in accuracy and consistency. Augmented feedback can be provided via technology in three modalities: audial, visual, and haptic. These can also be combined into multimodal feedback systems [2].

In this graduation project, the focus is on haptic feedback. Haptic technology concerns the interaction of computers and humans via touch or a sense of touch [3]. A haptic wearable specifically is a device that uses haptic technology to create a sense of touch and which is controlled by a computer [3]. Research in haptics is often still in its early phase. Advantages are found herein that stimulate doing more research. Firstly, haptic applications are often based on relatively simple technology [4]. Secondly, it has shown the potential to provide intuitive feedback [4]. For example, a tap on the right shoulder is immediately understood as moving or looking to the right. Thirdly, if designed well, the demanded cognitive load is often low. This means that it takes less effort for the brain to process the information, which makes learning easier [5]. On top of that, the low cognitive load is beneficial if the feedback is integrated in complex tasks, so the brain is not overloaded with information. The exercises and movements in sports are often complex. Therefore, it is interesting to research the use of haptic feedback in sports. Possibilities of appliance are in tactics, posture, and movement coordination [6]. For this project, the focus is on posture and movement.

It is chosen to design a haptic feedback application in volleyball, because of personal interest. There has not been developed a haptic feedback device for posture and movement in volleyball so far. The focus will be on the posture of volleyball players when they should be ready to go for the ball. In volleyball practice it is learned to shift the body weight to the forefeet, which results in an active posture to be able to quickly move to the ball. Learning to apply this movement correctly is a form of motor learning. For motor learning the same definition as in [2] will be used “Motor learning describes a lasting change of motor performance caused by training.” [2, p. 22]. In motor learning, the studied movement for this project would be a simple task. Most healthy human beings can shift their weight to their forefeet. However, when it is integrated into volleyball practice, one often forgets to do so on the right time [7]. In motor learning context is critical. It influences the perceived level of the task and advised learning method [8]. The goal of my graduation project is to design a haptic feedback system to stimulate volleyball players to keep their weight on their forefeet in play.

1.2. Problem Statement

In most sports situations more augmented feedback can be present. Nowadays, this feedback, if present, is provided by a trainer or coach. They can provide athletes with good feedback, but technology could add an additional layer of feedback. Technology offers possibilities in providing faster, more accurate and more consistent feedback. Haptics is an interesting modality, because feedback can be provided while performing tasks. The tasks in volleyball are often quite complex. If haptic feedback is designed well, the cognitive load is low, which makes it easier to understand the feedback and learn from it within complex tasks.

Almost no haptic feedback for posture and movement is available on the market yet and studies are still in early phases. Nevertheless, the initial studies show promising results that haptic technology can be effectively applied in sports to correct posture and movement [6]. More studies are necessary to enlarge the knowledge of how haptics can be applied in sports. Thus, it is relevant and interesting to explore this field. So far, it is not common to use technical supplies in volleyball practices at a medium level.

Therefore, development of feedback devices can contribute to new feedback and practice methods in general.

1.3. Research question

As a result of an initial orientation on the topic of haptics in sports, the research question (RQ) has been formulated. To answer the research question, different areas of interest are identified for which sub-questions (SQ) are formulated. All questions are listed below. The sub-questions will be discussed to gain more knowledge on the state-of-the-art, design features, and evaluation of a haptic feedback design.

RQ	*How to design a haptic feedback system that stimulates volleyball players to keep their weight on their forefeet during play?*
SQ 1	What is the state-of-the-art of haptic feedback in posture and movement in sports?
SQ 2	What are the possibilities for the technical design, e.g. choice of sensors, feedback principle and location on the body?
SQ 3	What is an effective way of providing feedback, e.g. concurrent or terminal feedback, giving feedback after a good, bad or all trials?
SQ 4	How can the haptic feedback design be evaluated?

1.4. The report

The report will overview what has been done to answer the main research question. This includes literature research, design phases, and experiments. In chapter 2, state-of-the-art, the SQ 1, 2 and 3 will be discussed one by one to gain more insight on the possibilities, limitations, and advices of haptic feedback designs. This is done with the help of the literature available and relevant information from the internet. Chapter 0 elaborates on the used research methods during the design phases, answering SQ 4. Next, the ideation phase is described in chapter 4. All aspects of the design are combined in a mind map with design choices. Then, various elements will be tested and discussed on their usability in a prototype, which leads to a specification of an initial prototype discussed in chapter 5. The process of realization of the prototype is described in chapter 6. This prototype is initially tested by one user of which the evaluation can be read in chapter 7. This evaluation leads to some direct changes to improve the prototype. In chapter 8, the implementation of these improvements are discussed and the final prototype is presented. With this prototype some final user tests are conducted and an elaborative description of the findings in this evaluation can be found in chapter 9. The report will be concluded with a discussion of the results from the literature and evaluation, which leads to a conclusion answering the RQ. This is included in chapter 10, which ends with recommendations for future research and implementations.

2. State of the Art

2.1 Haptic feedback applied in posture and movement in sports

Most haptic feedback designs in sports are still in an early design phase and used for studies only. They are not ready to be sold on the market yet. These statements exclude the smart watch, which can also provide haptic feedback through vibration. The relevant designs and findings in these studies are discussed in light of the different sub-questions. In this section, multiples haptic feedback designs that provide feedback on movement or posture in sports are described. One product is fully developed and for sale: the Nadi X [9]. Furthermore, Move of Electricfoxy has been showed in a museum to make people aware of current technological developments. The other designs that are elaborated were used in studies, either to improve the design or to study the effectiveness of haptic feedback in motor learning. The focus will be on describing the system used, not the results of studies conducted with the design. These are integrated in section 2.2.

Nadi X

Figure 1 Nadi X by Wearable X, Source: adapted from [9]

Nadi X is a legging developed for Yoga, see Figure 1. The legging helps improving the yoga skills by using subtle integrated sensors and haptic feedback system. A small device called ‘The Pulse’ can be connected to a phone via Bluetooth and attached behind the left knee on the legging. Vibrotactile feedback is used and the vibration strength can be personally adapted. The concept comes with an app in which multiple workouts are accessible. Audio instructions can be given to lead the workout. The vibrations can be felt over the full length of both legs and determine focus points during exercising. The Nadi X is on the market and can be bought for approximately 250 dollars per legging and 60 dollars for The Pulse. [9]

Move

Figure 2 Move by Electricfoxy, Source: adapted from [7]

Move is a wearable tank top as shown in Figure 2. The integrated technology guides the user toward optimal performance and movement. Haptic feedback technology on the hips and shoulders provide subtle feedback until the user performs the movement correctly. Stretch-and-bend sensors are implemented on all sides to track the users movement [10]. To control the system, a LilyPad Arduino is used [11]. Move is connected to an app in which the user can track his or her performance. The outfit sends measured data to the app. The initial design is focused on Pilatus movements, but it is mentioned that Move can also be used for precision and expressive movements; examples of appliance could be a golf swing, a pitcher's throw in baseball or a dance move. At this stage Move is a concept and it cannot be purchased [12], but is has been shown at the Technisches Museum Wien according to [13]. Although in [11] it is discussed that multiple prototypes of Move have been developed to be introduced to consumers, no record can be found of recent developments in this process. Disadvantages of producing such a device mentioned in [11] are that the textile industry is not equipped to include electronics in their fabrics. Also, electrical engineers and textile makers are not used to working together and the integrated electronics make washing difficult.

MotivePro

Figure 3 MotivePro by Birmingham University, Source: adapted from [11]

MotivePro, Figure 3, also called the Vibrating Suit, is a wearable full of sensors and actuators to provide athletes with live feedback on their performance. It can be used to improve techniques during training. When the user moves outside of a desired range the vibration motor turns on and guides the user in the right direction. The design developed at Birmingham University was tested by Mimi Cesar, an international gymnast. She found the device promising, especially for young gymnasts to learn understanding the body early on and thereby speed up the learning process. [14]

Golf putting

Figure 4 A planar four-cable haptic putting system. Source: Adapted from [10]

Figure 5 Overhead view of the putter with the four cables and a golf ball. Source: Adapted from [12]

Researchers designed a haptic assistance device to improve the putting accuracy of golfers. Both the design and evaluation of the design are discussed in [15]. The putter head is connected to four cables, as can be seen in Figure 5, which are connected to the corners of the metal construction, see Figure 4. In these corners the cables are connected to DC motors, which can control the wires. MATLAB has been used to program the software. The system is specifically designed for putting since it also allows movement and control in the horizontal plane. The golf club also needed small adaptions to connect the wires. The system could be useful to get an initial movement representation of putting a golf ball. However, [15] concluded from the user evaluation that there were multiple points of improvement. More studies are needed to eventually state that the system could be useful in training people to putt better.

Rowing

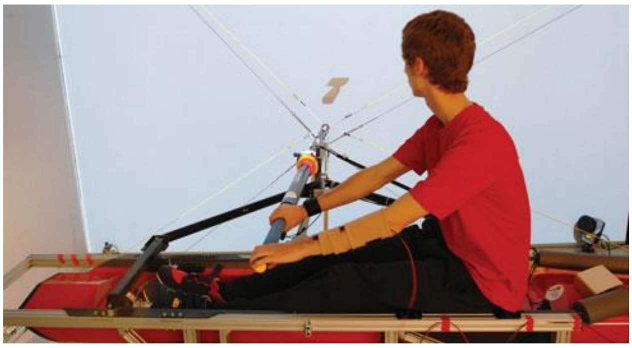

Figure 6 Haptic feedback design for rowing, Source: adapted from [13]

The rowing construction presented in Figure 6 uses two haptic feedback principles: mechanical and vibrotactile. This construction is used for research described in [16]. As can be seen in Figure 6, the end of the blade is connected to ropes just like the golf design. Haptic feedback can be provided by pulling the blade more strongly in the desired direction. The more the deviation, the stronger the feedback. Besides, the participants get feedback on blade orientation through vibration on the left forearm. In the construction the users only rowed with their body and arms, excluding the movement of the legs.

Tennis forehand stroke

Figure 7 Haptic guidance in tennis. Source: adapted from [14]

The haptic guidance system for tennis presented in Figure 7 uses ropes to guide the ‘racket’. It is specifically created to perform a dynamic tennis forehand stroke with a fully stretched right arm. This is chosen because timing is important in this movement. Three guidance strategies were designed and evaluated in [17]: Fixed haptic guidance by a postion controller, no guidance using a path controller to ensure safety and guidance as needed in which the amount of support was adapted. The system is designed for use in further research on motor learning and preferable feedback strategies, as done in [18], where the different guidance strategies are evaluated on optimality for learning a timing task. The results of this research and overall research on effectiveness of feedback strategies will be further discussed in section 2.2.

Skating

Figure 8 Setup for study in skating, Source: adapted from [19]

Haptic feedback in skating makes the user relive the experience. In [19], multiple feedback modalities were tested in providing feedback to skaters. The haptic feedback consisted of vibrations in the floor where the skater lands on. The vibrations are strong enough to pass these to the board and eventually the skater feels them. The set-up can be seen in Figure 8. The feedback makes the skater relive the attempt. Therefore, it provides the skater with information about how well the task was executed. By personally analyzing what can be improved, the skater can learn to perform skate tricks better.

2.2. Literature review

The literature review discusses the sub-questions one by one in separate sections. Firstly, SQ 2 on the technical design including sensing and haptic feedback mechanisms is discussed. Secondly, the literature on effective haptic feedback design is examined to answer SQ 3, elaborating on the influence of different design choices on the effectiveness in motor learning.

2.2.1. Technical design

The technical design concerns the materials needed to design a working product and the different possibilities herein. The technical design section discusses SQ 2 and is split into two sections: sensing and haptic feedback mechanism. The sensing concerns what should be sensed and how this could be done. Then, the possibilities in haptic feedback mechanism are discussed, including what could be a good placement of the mechanism and how this could be integrated into a wearable.

Sensing

For the project it is important to sense whether the user puts most weight on the forefeet. A significant amount of weight should be on the balls of the feet, not in the toes or heels. A prototype which senses this can be found in [20]. A detailed description is given of the process of the constructing a wearable between a sock and an insole which measures the pressure below one foot in three different places. In this design a pressure-sensitive conductive material, called Velostat, is used to create force sensors. The resistance within this material decreases when the pressure increases. [21] confirms that this type of material, 'Velostat Pressure Sensitive Conductive Sheet', is useful to create force sensors that measure heavy things, like the weight under the feet of humans. One sensor below the heel and one below the balls of the feet should be sufficient to measure the weight shift. A third sensor below the toes could be implemented to prevent over shifting the weight. However, it is not clear how often this happens.

The sensors could also be implemented in an insole, as done in [22] and [23]. The insole examples do not include a feedback system, in contrast with the system in [20], in which each sensor is connected to an LED, which turns on if a threshold value is reached. These LEDs and more technology is worn around the leg. Nevertheless, this could probably also be implemented in an insole.

There have also been shoes developed which include precise sensing of the weight division. NASA designed Force Shoes, [24], which can sense forces in all directions. The intention is to use these shoes in space to measure the forces astronauts experience during their daily exercises. The information is sent to computers via Bluetooth. A similar design can be found in [25]. This shoe is designed for potential use in rehabilitation. The advantage of the developed shoes is that it gathers detailed information on the weight division. However, the disadvantage for using these shoes in volleyball experiments is that they are not developed to be used in sports situations, which often require the right shoes to prevent injury. Regarding the possibilities, using Velostat, following a process similar to [20], seems most promising for the prototype. This is the cheapest to purchase and provides a lot of freedom in shape and implementation.

Haptic feedback mechanism

To get a better idea of how haptic feedback can be applied in sports by technology, some examples are discussed. Haptic feedback is mostly provided via vibrotactile motors and robotic installations. A specific haptic feedback concept, called haptic guidance or position control, provides feedback to guide the learner through the desired movement [2]. Examples of haptic guidance are found in golf [15], rowing [16], and tennis [18], all described in 2.1. In these three studies a robotic mechanism connected to the end of the paddle, club, and racket, respectively, provided haptic guidance. Other designs use vibration motors to provide haptic feedback, like in Nadi X [9] and Move [13]. This is also called vibrotactile feedback. The motors are directly attached to the body via a wearable and the feedback is felt through the skin. There are more possibilities than mentioned here. Every technique that creates a feeling of touch for the user, could provide haptic feedback.

The location of the haptic feedback mechanism must be carefully determined. The feedback system should not be hindering the user. The sensitivity of body parts and the number of locations where feedback is given should also be taken into account in the design. In [26], it is stated that participants in a study on violin playing did not want to use the vibrotactile feedback even though it improved their performance. They felt hindered in their normal movement by the placement of the feedback mechanism and experienced it as frustrating. In [15] the users of an initial design of a haptic feedback system for golf also felt partly hindered by the system. However, they were not frustrated but mainly suggested changes in the design for further studies on the subject.

For vibrotactile feedback, the body's sensitivity in different areas should be taken into account. The sensitivity has an impact on where and how intense the users perceive the feedback. The rhythm, roughness, intensity, and frequency of the feedback should be designed differently for different body parts [27]. [28] evaluates a design providing vibrotactile feedback around the waist. The intensity of the vibration should be higher than a threshold value to be sensed by the user. Besides, if multiple motors are used, there should be a minimal distance between them. This is elaborated in [29], where it was found that the accuracy of detecting the correct vibration motor was reduced as the number of motors was increased. Additionally, [29] found that the accuracy was significantly higher during walking in comparison with running and that staggered vibrations are more suitable if the user should be able to distinguish at which location the feedback is given and if the intensity should be sensed. Overall, many aspects influence the perception of the vibrotactile feedback. It seems best to decide on a location or multiple locations where feedback is provided and then take the sensitivity into account to define an optimal intensity, rhythm, and frequency. Vibroactuators are small and therefore easy to implement in wearables. This is appropriate for the project and could thus be used. It is interesting to focus specifically on the perception of vibrotactile feedback on the feet since the position of the feet is the most important aspect of the correct posture. Therefore, it will probably be most intuitive to provide feedback on the feet to change the user's posture.

Simple vibrotactile feedback patterns provided to the sole and on top of the foot can be sensed and interpret well. [30] describes the design of a feedback device for the foot's sole using vibrotactile feedback. The participants joined in multiple experiments to discover how precise data is perceived through the feet. It was found to work well for simple patterns, more complex patterns were harder to recognize. Therefore, the advice given is to keep the information simple and encoded as vibrating patterns. The foot does not seem able to distinguish which motor is vibrating, which makes integrating many motors ineffective. In [31], two foot protypes are compared. One provides feedback in the sole, the other provides feedback on top of the foot. There were no significant differences found in accuracy. For both it is important to be sure that the feedback mechanism touches the foot. This could be achieved by using a sock, suggests [31], where it is also that actuators on the sole of the foot should be at least 21 mm apart and on the toe 10 mm to be distinguished. If multiple vibration motors will be used, this is important to account for in the design.

A final important challenge is to design meaningful vibrotactile feedback. By meaningful the message the vibration tries to convey is meant. The location and properties of vibrotactile feedback can have an initial advantage by feeling intuitive for the user. However, users can also become more familiar with a vibration and learn how to interpret it. An important aspect is the polarity of a vibrating signal. A vibration can either attract or push away. Considering the position of the foot influencing the posture, a vibration on the heel can either be perceived as 'stand more on the heel' (attract to the vibration) or as 'avoid standing on the heel' (push away from the vibration). The intuitive preference is often individual. However, the message can be influenced by changing the properties of the vibration. If it is experienced as annoying, the user does not want to feel it and is pushed away from the location of the vibration. If the vibration is experienced as pleasing, it will sooner attract the body part to that location. [2] No preference is known for this specific posture and movement.

2.2.2. Effective haptic feedback design

This section discusses SQ 3, which questions what an effective way of providing feedback is. This is relevant since the goal is to use the haptic feedback to improve a motor learning skill. There are different possibilities in the design of a haptic feedback system which have different results on effectiveness in motor learning. These possibilities and results are discussed within this section.

Haptic feedback in motor learning shows promising results on effectiveness, but more research is needed. [6] provides multiple examples of applications of haptic feedback in sports. The different feedback systems used in football, cycling, ice skating, and rowing are proven to be quite effective. They could provide direct and intuitive feedback [6]. Although research is still limited, results so far are promising that haptics can be effectively applied in sports. The skill level of the user seems to influence the effectiveness of feedback designs in many studies. Therefore, skill levels are explained first. Then three important variables in designing a haptic feedback system are discussed regarding effectiveness: Giving feedback during (concurrent) or after (terminal) the execution of a task, the frequency in which feedback is provided, and providing feedback after a good or bad trial.

Three phases can be distinguished in motor learning and are relevant for the effectiveness of different designs of haptic feedback. The phases as described in [2] are used. In the first phase of motor learning the learner does not know how to perform the task. Feedback is used to form a first movement representation. In the second phase, the learner already knows the movement and can detect and correct mistakes in the performance. Feedback can improve the skills to detect mistakes and correct the movement. The final phase is when the learner performs the task highly automatically and consistently. No feedback is needed in this phase. The subjects in a study on a golf swing also noted the importance of taking into account the current skill level of the user [15]. The skill level influences the effectiveness of design choices and will be included in the discussion of the variables.

Concurrent haptic feedback should be designed to stimulate learning in the long term. This could be done by augmenting errors instead of preventing them, or by adapting the frequency of feedback. One specific form of concurrent haptic feedback is haptic guidance. This has a very instructional character. Therefore, it could be useful in the early learning phase [32] or in learning temporal aspects of a complex motor task [16]. This was also confirmed in [18], where haptic guidance in performing a complex tennis task seemed especially helpful for less skilled subjects. However, haptic guidance is suggested to be ineffective in long term learning [2]. The reason for this ineffectiveness could be that haptic guidance creates dependency, as mentioned in [2] and [33]. The haptic guidance prevents making mistakes, which prolongs the process of successfully learning motor tasks [2]. In [2], suggestions are discussed which might decrease the dependency. One suggestion is using the feedback differently. An example thereof could be decreasing the frequency in which feedback is given over time; starting with receiving feedback every time the mistake is made and later on only receiving feedback once in the five times the mistake is made. This stimulates the user to learn recognizing mistakes himself. Another suggestion is providing concurrent haptic feedback in which errors are augmented. This error augmenting strategy has been proven to be helpful in motor learning in general [34] as well as with haptic feedback [33]. So, concurrent haptic feedback seems to be effective if designed correctly. Most literature is focused on haptic guidance, while concurrent haptic feedback could also be used differently, for example as a reminder.

No conclusions can be drawn on the effectiveness of terminal haptic feedback. Few articles can be found on this topic. The skating system [19], discussed in 2.1, is the only system found in which haptics is used as terminal feedback. The users did like the detailed information this feedback offered on the execution of their skating trick. However, the effectiveness in motor learning is not studied. The further lack of studies might be explained by the exclusive advantages haptics can provide in concurrent feedback. No other modality can fully move the learner through a motion. This could lead the attention to the possibilities in this specific field. Besides, terminal feedback can easily be provided in other modalities, for which the feedback is already proven to be effective. For example, in research on performing a complex rowing task, it was found that terminal visual feedback was more effective than visual, audial, and haptic concurrent feedback [16]. Terminal haptic feedback was not studied. Considering the alternative possibilities in haptics and the availability of terminal feedback in other modalities, it might have less priority to research the opportunities of haptics in providing terminal feedback. Nevertheless, the results might be interesting. It would be worthwhile to study the possibilities of terminal feedback using haptic technology.

In designing the frequency of feedback, it could be effective to give control to the user, named self-control. Self-control means that the learner determines when the feedback is provided. Self-controlled feedback increases the motivation since the learner can choose which aspect he or she wants to focus on, which increases the involvement in the learning process [2]. However, in [35] it was found that it still dependents on what frequency the self-controlled user uses the feedback. Namely, the results showed that the users who choose a relatively low frequency of feedback had an advantage over users who choose a high frequency. This could be related to studies which state that frequently receiving feedback might cause the user to depend on it [33]. Besides, continuous feedback can be experienced as annoying [36]. [2] states that the frequency of feedback should decrease with increasing skill level to stimulate effective motor learning, which seems in line with decreasing the dependency and not using continuous feedback. It is not evident what frequency strategy works best, but there are some guidelines to base new studies and designs on. The frequency can be determined by the designer or by the user via self-control. Continuous feedback should be avoided and the current skill level of the user should be taken into account to determine an optimal frequency.

Feedback seems most effective in motor learning when provided after good trials. [37] and [38] suggest that feedback after good trials enhances motor learning. Whereas [2] stresses the importance to incorporate error-based learning, which includes making mistakes and making users aware of how to correct these, so feedback after or during bad trials. However, these studies only included good, or bad trials. [39] compares both and concludes that feedback after a good trial was most effective for putting a golf ball at multiple distances, especially for the more complex tasks. All results discussed good and bad trials are from studies that did not specifically use haptic feedback, but feedback in general. There should be more research towards this variable in haptic feedback specifically.

2.3. Conclusion state-of-the-art

In the state-of-the art chapter, the literature and current availability of haptic feedback systems in sports and motor learning have been discussed. This section concludes what has been found to account for when designing a haptic feedback wearable for volleyball players to keep their weight on the forefeet.

Sensing can be done in multiple ways. By testing it can be figured out what works best. It is most reasonable to start with testing Velostat sensors since these are cheap to purchase and offer a lot of freedom in implementation. The most commonly used haptic feedback mechanism is vibration. This should also be sufficient for this project since providing feedback at the location of posture correction is good and vibration is experienced well on the feet. It should still be determined on which spot on the feet exactly the vibration is perceived the best and most intuitive. The message the vibration tries to convey should be included in this process. Also, the vibration strength should be tested and used in a comfortable frequency.

There is a lot of discussion and unclarity on how haptic feedback can be best applied to effectively learn a motor skill, especially in the long term. The current skill level of users is relevant and should not be neglected in designing and evaluating the prototype. Haptics is often applied as concurrent feedback where it offers the largest advantage over visual feedback. However, terminal feedback could also have the desired effect. It is an option to design two software programs for the prototype, one with concurrent and one with terminal feedback. This could lead to more insight in which feedback is preferred by users.

Continuously providing feedback is ineffective. It is better to implement a fading pattern or to switch between using the feedback system and not using it. It can be chosen to use a self-control frequency in which the user decides when to use the feedback. The project will be mainly about designing a system, so the effectiveness of the prototype is most interesting to implement later on. The next steps within this project are prototyping and evaluating the prototypes.

3. Methods and Techniques

To evaluate the results in different design phases of the prototype different techniques can be applied. It is chosen to start with an auto-ethnographical approach in experimenting and conduct user tests with a more developed prototype. Below both methods will be elaborated.

3.1. Auto-ethnographical experiments

An auto-ethnographical method will be used to create a working and safe prototype. This is a method in which the designer self-reflects on the experiences and outcomes during the testing process. It is important in this method that the researcher tries to emphasize with the user, which eventually also increases the engagement with the user [40]. This means that the designer should reflect on the design with a broader view than just the personal opinion. For some decisions for the design, it might be hard to decide what the users will prefer. Such a situation should be noted in a reflection and might be useful input for the user tests.

The auto-ethnographical approach will be used in the ideation phase (section 4). Per element it will be discussed what the goal is of the experiment, which set-up has been used and what the results are. Eventually, there is a conclusion on whether the element is suitable for the prototype. This approach is for example used to determine the placement of the sensors in the prototype. The auto-ethnographical method is used for this phase because it is time efficient.

3.2. User tests

To evaluate the use of the prototype in volleyball situations, tests will be conducted with users. These tests will have two parts: testing the prototype and an interview. To test with users it is important to mind ethics. The ethical committee of the faculty EEMCS of the University of Twente has approved the plans for the user tests. The brochure and informed consent form can be found in appendix A. After each user test the prototype could be adapted to improve the prototype as efficiently as possible.

To test the prototype, the participant will be asked to wear the prototype and the feedback system will be introduced on how it works. Then the participant is asked to perform some exercises with it, in which standing on the forefeet is a critical part. If there are any notes from the participant or relevant observations by the researcher, these will be noted. After the tests with the prototype a semi-structured interview will be done with the participant. A semi-structured interview is a time consuming method to prepare, conduct and analyze. The questions need to be prepared, but in the interview there should be freedom for discussion. Everything that is raised should be noted and if useful taken into account. [41] The interview will be voice recorded and summaries are made. A detailed plan and the questionnaire for the user tests can be found in appendix D.

4. Ideation

In this chapter, the first phase of the designing process is discussed. This phase starts with a mind map which explores the design possibilities. Then, design options from the mind map are further explored. They are tested in experiments to determine whether they are suitable to create an initial prototype.

4.1. Mind map

As a start of the ideation phase a mind map has been made, which can be found in Figure 9. It consists of the different design questions and possibilities that raised from the literature review and that came up during brainstorming. Design options mentioned in this mind map will be tested in experiments. If a system or material is found to be suitable to implement in the prototype, it will be used. If not, another option mentioned in the mind map for the same purpose will be tested until one is found that fits.

Figure 9 Mindmap design choices

4.2. Pressure sensor

To determine whether the user has the correct posture, sensors that measure the weight shift below the feet can probably be used. In the literature, multiple options were found to measure weight shift: bought force sensors, force sensors made with Velostat and existing force shoes. It has been chosen to start with exploring the option of creating a force sensor with Velostat since this is cheap. Besides, Velostat gives a lot of freedom in the shape of the sensors, which is great for fitting them in the prototype. The main goal is to find out whether these sensors can indeed be created and are accurate enough for use in the prototype. First, the sensors will thus be made and connected to an Arduino Uno. Hereby, the circuit can be determined and the sensitivity to pressure can be examined. Secondly, they will be tested below the foot to analyze the values.

Experiment 1: Circuit Velostat sensor with LED

The idea of using Velostat to sense the pressure is gotten from a project described in [20], in which three Velostat based sensors are attached below the foot. Each sensor is connected to an LED and when a sensor reaches a threshold value the connected LED turns on. In Experiment 1, it is figured out what circuit is needed and whether the Velostat seems promising to act as force sensor for this project.

Setup

The setup is based on the aforementioned project [20]. The values of the sensor are printed to the Serial monitor of the Arduino. An LED is included in the circuit to test whether a threshold value could be set to turn the LED on and off. The material used to create and test one sensor and the fritzing of the setup can be found in Figure 10.

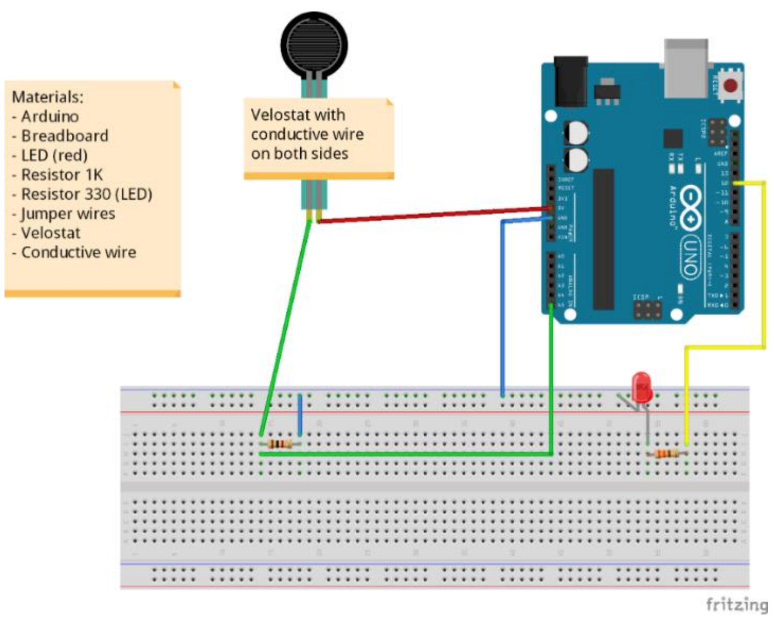

Figure 10 Arduino Fritzing of Velostat Pressure sensor and LED connection

Results

By reading the values from the Serial monitor, it could be quickly found that the Velostat sensor connected in this circuit is pressure sensitive. By looking at these values, a threshold value can be chosen to turn the LED on when a certain pressure is exerted on the sensor. However, the Velostat gave very variable values. When lightly touching the values varied between 530 and 550. When firmly pressing with four fingers the values varied between 300 and 330. This could be stabilized by adding a filter function to the Arduino software. After implementing a filter function, the values became indeed much more stable without filtering the influence of pressure on the material. It is important that the conductive wires connected to the sensor do not touch at any time since that creates a shortcut. This is important to account for when implementing the sensor in a wearable. It is good to note that the sensed value will probably be different for people with different weight. Also, the material needs some time to come back to its initial value after a firm press.

Conclusion

A sensor created from Velostat does accurately measure pressure. A filter function needs to be integrated in the Arduino software to get more stable values. The two wires that are attached to the sensor should never touch. Besides, attention should be paid to influences of different weights of users. Also, the sensor seems sensitive to get tired after it is intensely pressed. This might have an influence when the sensor is used for a longer period of time.

Experiment 2: Pressure below the foot

The next goal is to gain more insight into the functioning of the Velostat sensors below the foot. It should be determined whether the posture can be accurately measured. Also, the influence of different weights and body shapes can be shortly tested.

Set-up

To measure a difference in pressure below the foot, a second sensor is added. One sensor is meant to be placed below the ball of the foot and the other below the heel. The second sensor is added via a similar circuit to Experiment 1. The sensors are both sewed into non-conductive fabric from an old t-shirt to prevent conduction via the skin. In Figure 11, the sensor sewed into fabric for below the ball of the foot can be seen. Figure 12 shows the circuit with both sensors connected to the Arduino via a breadboard. The sensors are cut out to fit best below the foot, one in the form of a heel (left) and one in the shape of the ball of a foot (right).

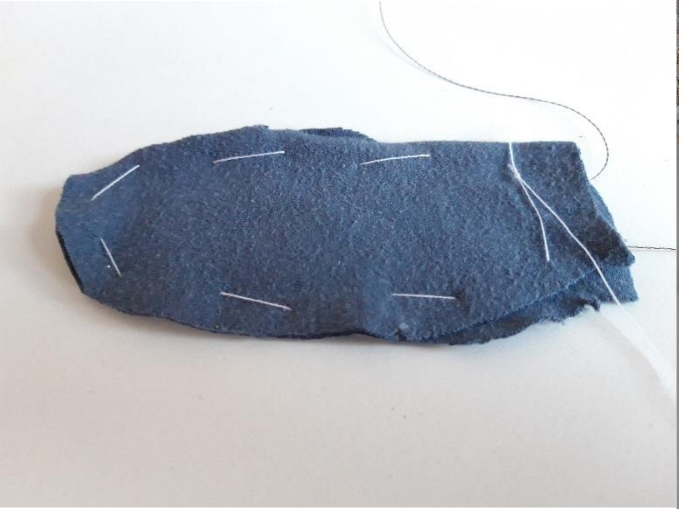
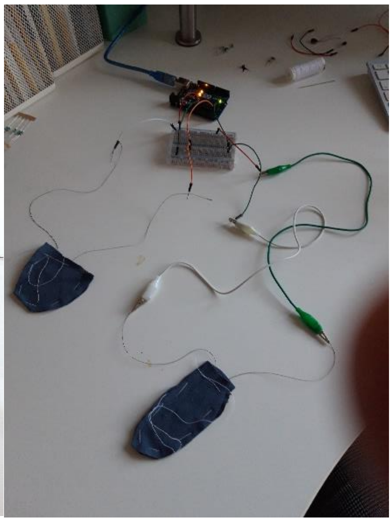

Figure 11 Ball sensor sewed in non-conductive fabric

Figure 12 Heel and ball sensor sewed in non-conductive fabric connected in a circuit

Firstly, the influence of the non-conductive material on the sensor values will be determined. Secondly, the sensors will be tested below the foot. This is done by putting the sensors on the ground and positioning them correctly below the foot. They are not attached to the foot or sock. In the test no shoes are worn. For three body positions the values of the sensors will be tested. The body positions are described below and can be seen in Figure 13, Figure 14, Figure 15 and Figure 16. Three people will contribute to the tests to detect differences between different users.

1. Standing straight up with the weight divided equally over both feet
2. Standing straight on one leg
3. Standing on the forefeet with two legs


Figure 13 (Left) Position 1

Figure 14 (Right) Position 2

Figure 15 (Left) Position 3, front view

Figure 16 (right) Position 3, side view

Results

First, the influence of the non-conductive material was tested. The material is found to change the initial values of both sensors with more or less 50. The pressure is still sensed as well as before adding the fabric. This will most likely not influence the results of the tests below the foot and is therefore neglected. Secondly, the sensors have been tested below the foot. The detailed results of this test can be found in appendix B. The range of values between the three users for the three body positions can be found in Table 1.

Body position	Heel sensor value range	Ball sensor value range
1	42-46	18-20
2	38-41	13-19
3	52-103	13

Table 1 Range of sensorvalues for three postitions for both sensors

As can be seen in Table 1, the ranges of the values are small, while the differences in values between the body positions are significant. Only the heel sensor in position 3 shows a large variety in values. This can be declared by the amount of weight that it shifted. In observations it could be seen that users tend to have different postures when asked to stand on the forefeet. It could be further determined which value is most appropriate for the posture in volleyball in the user tests.

Especially the difference between position 1 and 3 is relevant for this project. For all participants the heel value is higher and the ball value lower in position 3. In general, it can be seen that the difference for the heel value is higher than for the ball value.

Considering these data, there are two interesting options for sensing the body position of the user correctly:

1. Divide the heel value through the ball value: The more the participant has his weight shifted to the forefeet the higher this value
2. Use the heel sensor for comparing since the differences are larger. The more the participant has his weight shifted to the forefeet the higher this value

Both options are dependent on the amount of weight that is shifted. It might be necessary to do a small initialization with the values at the beginning of a user test to make sure that the feedback is provided at the right threshold value. Besides this finding, it became again clear that the material gets tired after pressure is exerted. However, the body position can still be correctly measured.

Conclusion

The sensors made from Velostat can be used in the prototype. The differences between the values are significant for the different postures: standing straight and standing of the forefeet. Differences in weight and body sizes have no significant influence. The amount of weight that is shifted is more relevant. The sensors are not maximally accurate and the material tends to get tired when extensively used. This can be accounted for by checking the values before the user tests and possibly adapt the software to provide feedback correctly. Two options are given to determine a threshold for the feedback to be provided. It should be checked whether these options are also appropriate for new created sensors. Luckily, this is something which can be adapted in the software.

4.3. Feedback mechanism: vibration motor

In the literature it was found that vibration is the most used haptic feedback mechanism. It seems also fitted for this project since it can be well perceived on the feet and easily implemented in a wearable prototype. Firstly, it is discovered how to get the vibration motor working with the Arduino Uno. When it is working, it will be manually tested on different places on the foot to find out how the vibration is perceived: feeling and intuitiveness.

Circuit Vibration motor

A vibration motor can be connected to the 5V and ground pin to make it vibrate. When connecting the red wire to a PWM pin and the black one to ground, a simple program can be programmed and uploaded to the Arduino to control the vibration strength and pattern. However, connecting the vibration motor directly to the Arduino could damage the Arduino due to a different current that is used [42]. Therefore, a transistor should be added to the circuit. This results in the circuit as shown in Figure 17. This circuit works well and the vibration strength and patterns can still be easily controlled. Therefore, this circuit can be used in experiment 3 and in the prototype.

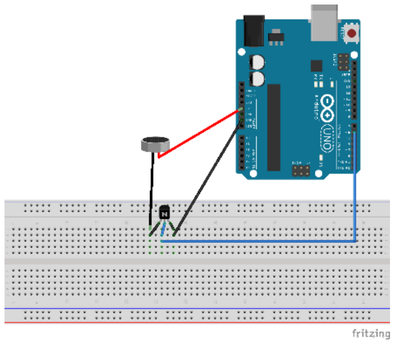

Figure 17 Fritzing of vibrationmotor circuit with transistor

Experiment 3: Location vibration motor

For the placement of the vibration motor two factors are important according to the literature. The vibration should be felt well, but not experienced as annoying. Besides, it should have an intuitive effect on the desired change. Meaning that it should be placed in a way that users tend to move their weight to the forefeet. There is an interesting difference in whether users want to be attracted to the right posture or pushed away from the incorrect posture by the placement of the vibration.

Set -up

First, a preferred vibration strength will be determined. The vibration strength can be changed within the Arduino program. The strongest vibration possible is felt when setting the value to 255 and no vibration is felt at 0. Secondly, the best placement of the vibration motor is tested by manually placing the vibration motor on different places on the foot and noting the experiences. The places that will be tested can be seen in Figure 18. To test the intuitiveness of the vibration on a place, the user was asked to make a weight shifting movement while experiencing the vibration. Location 10 and 11 would need the vibration to provide feedback with the meaning to push the user away from the place of the vibration. Locations on the upper forefeet would have to convey a message that the body should be attracted to the vibration. Three users will be exposed to the vibration on multiple places.

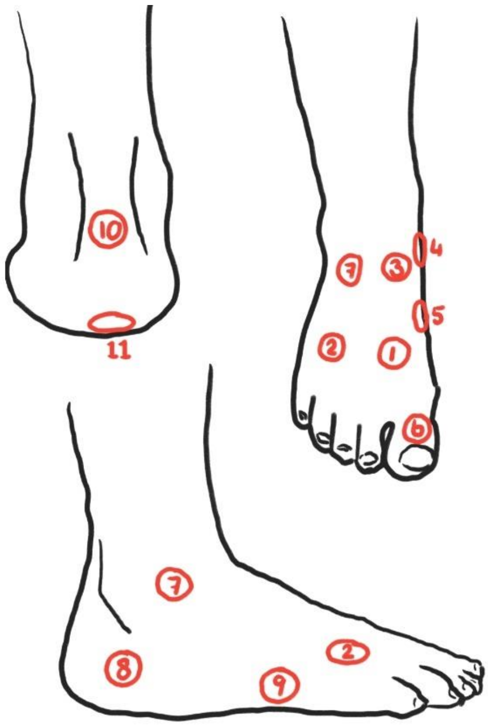

Figure 18 Numbered locations where the vibration motor is tested

Results

It has shortly been tested what vibration strength felt best. 50 was experienced as very soft and not very noticeable. 100 could be felt well and was overall not annoying, only at a few locations it was experienced as annoying. 200 was very noticeable, but a bit too much. Therefore, it has been chosen to use 100 throughout these tests. It might be experienced differently when the vibration is used in the context, so while performing exercises. That should be considered in the user tests.

The detailed results of the feeling of vibration at the different locations and the intuitiveness can be found in appendix B. At locations 4, 5, 6 and 9 the vibrations have been experienced as uncomfortable. Other places were mostly fine, but 1, 2 and 11 were clearly preferred. For the intuitiveness the same locations, but also 3, 7 and 10 were mentioned to be potentially useful. Overall, 11 was clearly preferred, closely followed by 2 on both intuitiveness and feeling combined. In Figure 19Figure 20, these two places have been showed in the test situation. Both convey a different message regarding pushing and pulling. Overall, the vibration has not been experienced as a pleasant and desired feeling. Therefore, position 11 has an advantage over 2 since the message would be to repulse the vibration.

 

Figure 19 (Left) Vibration motor places at location 11

Figure 20 (Right) Vibration motor placed at location 2

Since it is preferable to let the volleyball player use their own shoes during user testing to prevent injury, it has been tested whether the vibration motor could fit in the shoe at these two places. Since the vibration motor is very small (10mm) this is easily doable and will probably not hinder the user.

Conclusion

For this experiments it was chosen to use a vibration strength of 100. The vibration could be clearly felt, but was not annoying. It should be noted that this was a very clean experiment. When there is more context, the strength might need to be stronger to perceive the vibration well. Location 11, at the bottom of the heel, see Figure 18, was preferred on both intuitiveness and comfort. Also, it seems best to convey this repulsive message since the vibration was not experienced as pleasant or attractive. There is room for a vibration motor at that place in the shoe without hurting or bothering the user. Therefore, the vibration motor can best be placed low on the heel in the prototype.

4.4. Controller and power supply

An Arduino Uno has been used for the circuits in the experiments. This is not ideal to implement in the prototype. The Arduino has a large size, which could be hindering or annoying. Besides, the controller does not need to control many different or complicated elements. Therefore, it is interesting to explore the options in smaller controllers. Possibilities can be found in ATtiny, Adafruit and Arduino models. In this section, these possibilities are elaborated to decide which controller will be used in the prototype.

Firstly, the possibilities with ATtiny13a have been explored. The size is ideal, because it is very small: 2.5 by 1.7 cm, weighing only 1g. It has 8 pins that can be programmed, of which two are compatible with PMW and four with ADC conversion. So far, the prototype would consist of one vibration motor which needs a PMW connection and two sensors needing an analog input pin which could be read via an ADC converter.

The ATtiny13a should thus suffice to control these elements. However, programming such a chip is very different from Arduino. No Serial port is available and the pins need to be subscribed with tasks. In testing, the chip was successfully initialized and the vibration motor working. The gathering of analog data from the chip was a challenge. Due to time constraints, it has been chosen to switch to another controller. Also, in the future of user testing it would be a difficult to calibrate the sensors or add a functionality if this is necessary. So for the prototype this chip will not be used. Nevertheless, the ATtiny13a has the potential to be used in a final product. The size is amazingly small and the options are sufficient if the elements stay more or less the same.

The Arduino Nano can replace the Arduino Uno easily since it is almost completely the same but smaller. The same code can be used to program the Arduino nano if it is wired similarly. A disadvantage is that the Nano still needs quite a large power source. For the user testing this can be implemented with a 9V battery. These are safe to use for humans, however, due to size and durability it is not ideal for a final product. The Nano can be connected to a laptop via a cable to read values from the Serial monitor and to upload updated codes to the wearable. These possibilities are useful for debugging problems and calibrating the prototype.

Adafruit is a company that designs many small controllers, which can also be connected to the laptop directly. It is even compatible with the Arduino software program, however, it misses some functions to keep the costs lower. The software for Adafruit controllers would preferably be written in Circuitpython, which also includes a build in Serial monitor. The Adafruit trinket M0 would suffice for this project. It is twice as small as the Arduino nano. It has fewer pins, but enough for this project. However, due to time constraints, the prototype will first be created with an Arduino nano. If the size of this controller or the battery connection causes problems, the Adafruit trinket M0 should be explored further.

5. Specification

Before assembling an initial prototype the findings and conclusions from the state-of-the-art and ideation phase are summarized in this chapter. Next, a concept of the prototype is described and sketched, including a fritzing for the hardware and an overview of the interaction.

5.1. Requirements

There are several requirements the prototype has to suffice. In the ideation phase solutions have been found for them. Both the requirements and solutions are listed below.

- The prototype should sense the weight shift below the foot correctly.
    - Using two Velostat pressure sensors to retrieve sufficient data and using the data correctly in the software.
    - Calibrate the sensor values before the user tests in the software.
- The prototype should provide clear and intuitive feedback to correct the posture
    - The vibration motor is placed low on the heel, which gives a push like feeling to lift the heel.
- The prototype should consist of small and light elements to implement them in a wearable.
    - The sensors and vibration motor are small and will be connected using flexible conductive wire. The microcontroller and power source are larger, but they have more space, because they will be placed outside the shoe on the lower leg.

To be able to provide feedback when needed the prototype has to sense correctly what the current posture is. The prototype should be able to distinguish if the correct amount of weight is on the forefeet or not. Experiment 2 resulted in more insight how this can be achieved. Two sensors should be implemented: one below the heel and one below the ball of the foot. The data of the sensors can either be combined or the data of only one sensor can be used to program the software. To increase the precision, a calibration will be done at the start of each user test. Besides, the haptic feedback provided should be clearly felt by a user, but preferably also encourage an automatic shift towards the correct position. This is tried to accomplish by placing the sensor low on the heel to imitate the feeling of pushing the heel upwards, as found to feel most intuitive in experiment 3. To assemble all parts into one prototype it is also important that the elements are small, so they can be easily implemented without hindering the user.

5.2. Initial prototype design

The initial prototype will be a sock. This sock can be worn inside the volleyball shoe of the user, possibly over another sock to prevent the prototype to get sweaty. A schematic representation of the prototype design can be found in Figure 21. The sensors are placed on the location of the heel and ball of the foot and the vibration motor is sewed at the lowest point of the heel. All elements will be controlled by an Arduino Nano, which is sewed to the top of the sock, outside of the shoe area. Next to that a pocket for a 9V battery will be placed. This way the battery is changeable if necessary. All elements will be connected via conductive wire and soldered to the Arduino Nano, except from the battery. A battery clip will be connected to the Arduino, which can be easily clicked on and off the battery. This will act as a physical on/off button.

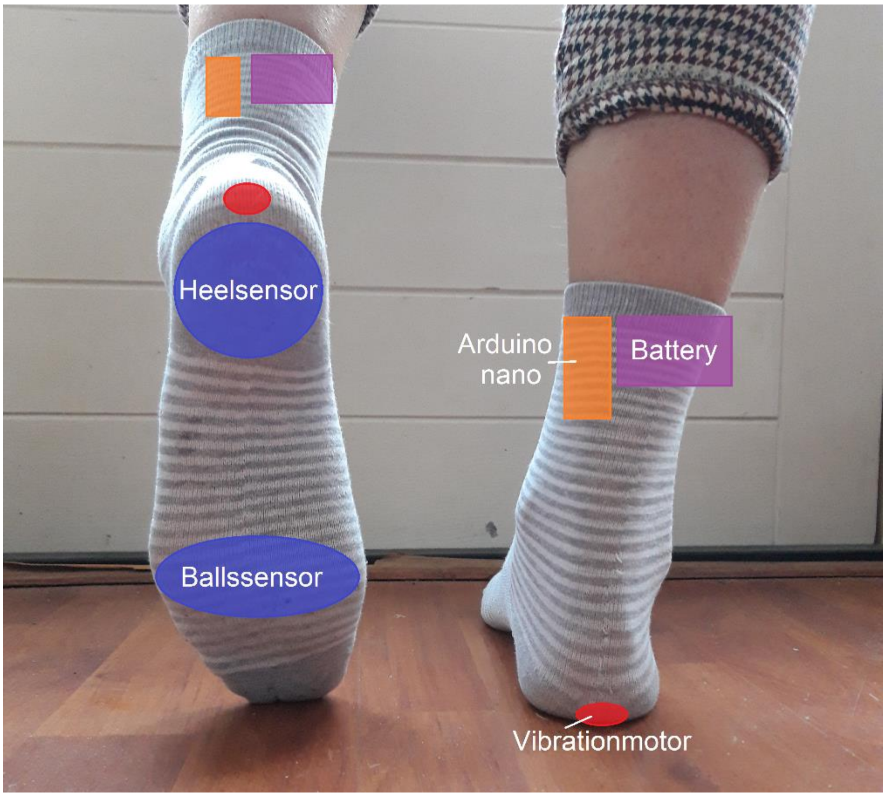

Figure 21 Placement of elements on the foot

5.3. Hardware connections

In Figure 22, a Fritzing of the hardware in the prototype is shown. In this Fritzing a breadboard is used to keep the connections clear. In the prototype, no breadboard will be present and the elements that are connected via de breadboard are then soldered together. If necessary additional wires are added to connect the elements. Eventually, only one wire is connected to a pin on the Arduino nano, same as in the Fritzing. The software that is uploaded to the Arduino can be found in appendix E.1. With this software the vibration motor turns on if the heel sensor drops below a set threshold value. This software will probably be adapted after realizing the first prototype. This is dependent on the values that come from new made sensors.

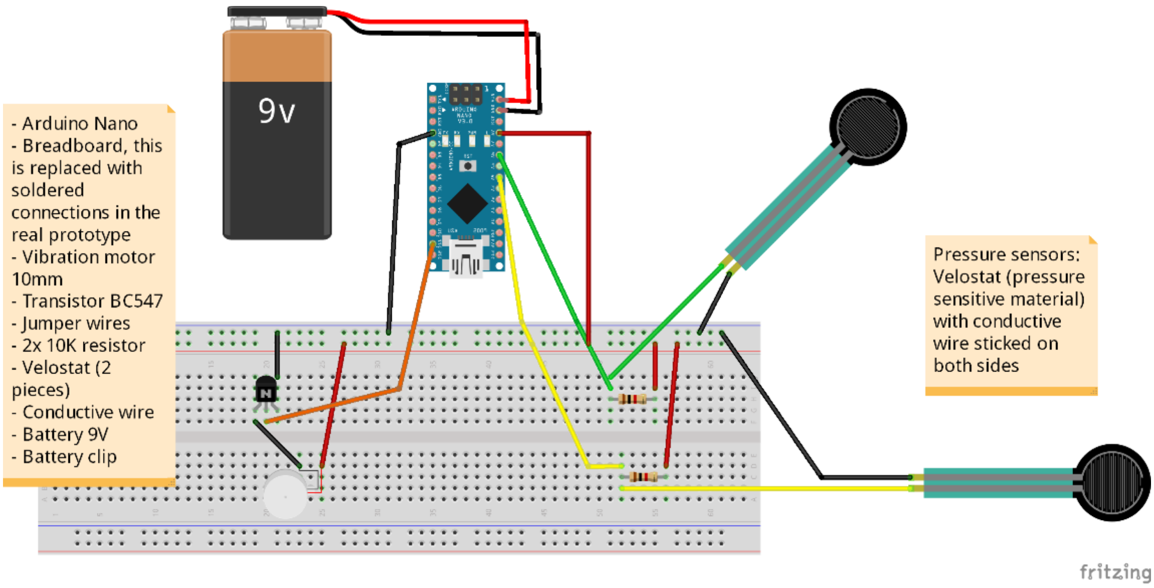

Figure 22 Fritzing of the hardware for the prototype

5.4. Interaction system

In Figure 23 an overview of the interaction of the user with the prototype is shown.

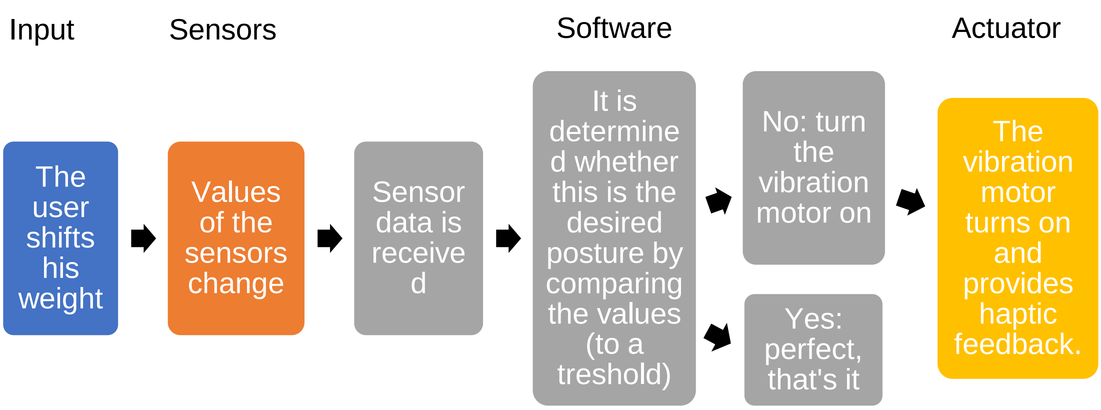

Figure 23 Overview of interaction with prototype

6. Realization I

With the specifications from chapter 5, a prototype can be made. The steps and difficulties within this realization process of the prototype are described in this chapter. Also, some pictures have been added to provide some more insight in the looks of the prototype. The breadboard circuit as shown in Figure 22 has been used to test elements in the prototype by connecting them individually to the breadboard circuit with alligator clips.

6.1. The realization process

First, new sensors are created from the Velostat and conductive wire. Besides that, a piece of fabric is cut in the shape of the sole of a foot with additional length from the ankle on. All electronics will be attached to this fabric. The fabric and locations of sensors, vibration motor, resistors and transistor are shown in Figure 24. The location of the sensors and vibration motor have been determined by putting the fabric below a foot and mark the correct placement. The location of the vibration motor is low on the heel, so this is where the fabric will be 90 degrees tilted to follow the form of a foot. When all wires and elements are firmly attached, this fabric as a whole can be stitched to a sock.

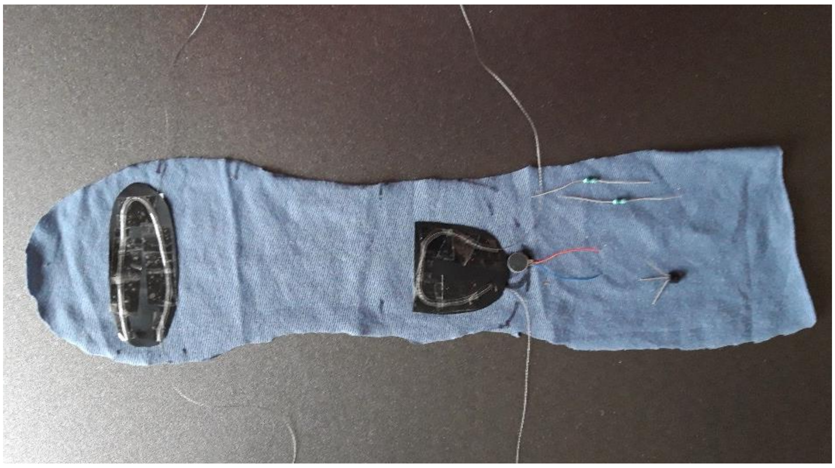

Figure 24 The fabric and sensors, vibration motor, resistors and transistor on the planned location

The sensors are attached to the fabric by sewing it over with an additional piece of fabric with the same shape. The conductive wires that are attached to the sensors are then sewed along the borders of the fabric towards the additional fabric that is available above the heel. The resistors and transistor will be attached to the corresponding elements there at this additional fabric.

Next, all elements are connected using conductive wire. Per attachment it has been shortly tested whether the separate element is working properly and thus whether the connections are good. With conductive wire, it is important that the wires do not touch each other since it is not protected with an isolation layer. Crossing and thus touching wires can result in shortcuts in the circuit. Also, it should remain clear which wire should go where throughout the process. There is no difference in color to show this. Therefore, the wires are carefully sewed in a pattern that prevents crossing wires and the tails are provided with a piece of tape with the connection name on it. The wires which should be connected to the same pin on the Arduino are tied together. This is the case for the ground and 5V connections. This way only one wire has to be attached to the Arduino. The prototype in this state, can be seen in Figure 25. The conductive thread is thin and nearly invisible. The resistors and transistor are on the other side than the Arduino nano, so they are invisible if the fabric is attached to the sock. Tape has been used a lot in Figure 25 since the wires were not soldered yet.

Figure 25 Fabric with elements connected to each other and attached to the fabric

To create reliable solid connections between all elements, the connections need to be soldered. While trying to do so, it is found that the conductive wire made of stainless steel is hard to solder. The thread keeps jumping away and a stable connection between the wire and an element or Arduino pin is hard to make. Also with the tips from a YouTube video [43], the connections seem week and unreliable to use in the prototype. The prototype should be resistant to some pressure since the sock should be worn by users and in a shoe. To guarantee a more stable prototype, it has been chosen to switch to thicker wires. These do have an isolation layer, which is not removed since thicker cables are not appropriate for sewing. Without isolation layer, it would be hard to prevent shortcuts. The thicker wires are attached to the fabric with tied-ups to keep them in place. The conductive thread is still used for the sensors for two reasons: the thread can better be sticked to the Velostat and below the feet it is uncomfortable to have thicker wires. These threads have been attached as stable as possible by using a lot of solder and letting no room for the wire to escape. Eventually, the battery clip is soldered to the Arduino nano and the fabric is attached to the sock. A battery pocket has been made of fabric to put the battery in.

6.2. The resulting prototype

In Figure 26Figure 27, the first version prototype can be seen. It consists of one sock. It will be evaluated through a user test whether one sock might suffice in providing feedback. It will also be determined in this test what can be improved to the current design.

Figure 26 The top op the first sock prototype

Figure 27 The bottom of the first sock prototype.

7. Evaluation I

The first evaluation chapter discusses the results of the first user test regarding the prototype. The plan for the user tests as described in appendix D is followed. This initial user test pointed out multiple points of attention which should be directly implemented to improve the prototype. These are discussed in this first evaluation chapter. The user was also asked about possible implementation of the prototype in volleyball practices. Such information from the interview has been processed in chapter 9, Evaluation II.

7.1. Prototype evaluation

A distinction has been made between the three different phases within a user test to describe the experiences of the user and mainly the issues that occurred during these phases.

Putting on the prototype

As soon as the user had put on the sock and both shoes and started walking around, the user noted that it felt like one leg was higher than the other leg. This is probably caused by the prototype which add an extra layer on one foot, which is missing at the other. It was suggested to also wear an extra sock on the other foot to regain a feeling of even legs. This helped and the user did not have the feeling that the legs were uneven anymore. Therefore, an additional sock should also be worn in other user tests.

During the exercises

During the exercises, the battery fell out of the pocket multiple times, which was experienced as annoying. It also influenced the movements of the user. These became more cautious, because the user wanted to protect the prototype from breaking down. It was established that the shoe pushed the battery out of the battery pocket, because the battery pocket was attached too low on the back of the sock. To be able to continue with the user test, the loose battery has been temporarily fixed by taping the battery to the sock. It would be better to attach the battery higher on the sock, so it does not interfere with the shoe. Besides, the battery should be attached more securely, so it will not influence the movements of the user.

Interview

The interview pointed out that the user tended to move with one foot only, the right foot, on which no feedback system was present. The user thought this was mainly because the system also vibrated when the foot of the user was in the air, so when walking or running as well. The vibrating feedback was experienced as wrong and therefore feeling this feedback was prevented. This is good, because eventually the feedback should be experienced in a way that the user wants to prevent feeling it. However, the feedback should then be provided at correct moments which was not the case. Therefore, it is important to change the software, so the vibration is not experienced when the foot is in the air.

Besides, the user experienced that he wanted to prevent feeling the vibration and therefore tried to keep the weight nicely shifted to the forefeet with the foot that had a feedback system. However, this was compensated in the movements by using the other foot more when moving backwards. This indicates that feedback on both feet is necessary to improve the posture, otherwise the foot without feedback tends to compensate, so the other foot will not experience the vibration.

7.2. Essential improvements prototype

The evaluation of the user test led to three main points that need to be integrated into the prototype directly. These points are listed below. Improving these aspects will improve the quality of the prototype significantly and are essential to provide feedback with the goal of stimulating an active posture. The process of implementing these improvements and the resulting prototype can be found in chapter 8.

- The battery should be attached higher and more secure.
- The vibration motor should be off when the foot is in the air.
- A second sock with the feedback system is needed to provide feedback to stimulate the active posture.

8. Realization II

The prototype needs to be improved on the aspects mentioned in section 7.2. The battery needs to be attached higher and more firmly. The feedback system should not vibrate when the foot is in the air and a second sock is needed with the same functionalities. Adaptations to the sock to meet these requirements should create a more stable and reliable prototype, which can be used in further user testing. Both the steps to implement the improvements and the resulting prototype are discussed in this chapter.

8.1. Enhancements prototype

The battery has been more secure attached by using strong elastic material instead of a sewed battery pocket. One elastic band goes over the length of the battery and lays in between the snap connectors, which provides certainty that the battery cannot fall out of the elastic bands if the battery clip is attached. Elastic is chosen, so the battery can still easily be replaced if necessary. Besides, the battery is attached higher to make sure that the prototype fits in every low shoe. The battery is attached to the sock itself instead of the additional fabric to get this done. These two adaptation should guarantee a more secure attached battery, which does not interfere with the shoe.

The software for the Arduino nano has been slightly adapted to prevent vibration when the foot is in the air. This has been done by adding an extra condition in the if-statement. The values of the sensors are higher when the foot is in the air. By checking these values, an upper boundary can be set. If the measured value is above this upper boundary, the foot is in the air and no vibrating feedback should be provided. The upper boundary value can be adapted based on the values from the initializing phase to ensure that it works. The additions and adaptions to the software can be found in appendix E.2.

Lastly, a second sock has been created for the right foot following the same process as used in chapter 6. The changes as described above have immediately been integrated in this sock. There is one large difference between the two socks. The right sock has the resistors and transistor placed on the outside of the fabric, which makes them more visible. This has been done so that the prototype can be more easily repaired if it breaks down during the user tests.

8.2. The prototype

An enhanced prototype is made by implementing the suggestions as described above. In
Figure 28 Figure 29, the prototype is shown while wearing it. Below the foot, the stitches around the sensor are visible. The battery attracts most attention since this is by far the biggest element on the prototype. On the top of the sock no technology is integrated. When looking closely at Figure 29, it can be seen that the right sock seems a bit messier.

This is caused by the elements that are attached on the outside of the additional fabric in contrast with on the inside, which is done for the left sock. This prototype will be used in further user testing and evaluation.

Figure 28 Back view of the prototype

Figure 29 Side view of the prototype

9. Evaluation II

In total five user tests are conducted, including the user test partly discussed in chapter 7. In this chapter, the results of the user tests are discussed. It is divided into four sections. 9.1 provides more insight in the volleyball background of the users. In 9.2 and 9.3, respectively the prototype and the feedback system are evaluated based on the notes during the exercises and the interviews with the users. Besides, the users have been asked about the possible future implementation of the prototype in volleyball. Their opinions and suggestions can be found in section 9.4. Summaries of all user tests are added in appendix F.

9.1. The users and user tests

People who are known to play volleyball at an association have been asked for the user tests. Everyone has been out of practice for a couple of months, because of the Covid-19 regulations. In this section some background information will be given on volleyball experience and level of the users, gathered from the interviews. Besides, a summary is given of the opinion of the users on the feedback provided in their current practices and what the users thought of the exercises in the user tests.

Users with a variation in level and experience have contributed. The data about this is classified for references in the rest of the evaluation. Two users had over 10 years of volleyball experience (advanced), one user for about four years (intermediate) and two users just started playing volleyball (novice). This is separated from the level of volleyball the user's play, which is based on the competition they play in. The ranking of these levels is based on the difference in between the five users. One advanced user plays 'promotieklasse' (high), the other advanced and the intermediate user play 'derde klasse' (medium) and the two novice users both play in the 'vierde klasse' (low).

Despite the differences in experience and level, all user experienced the exercises in the user tests as basic and doable. The plan was to do the user tests in a sports hall. This was impossible and is changed to an outside location. Eventually, all user tests are done in paved gardens. This is a different situation than normal volleyball practices. However, this has not influenced the results since the weather circumstances were good and the exercises were simple. No user mentioned to be hindered or influenced by the different location.

All users practice about two times a week. The two experienced users are also volleyball trainers. Therefore, they can provide more insight from a trainer's point of view. All users play volleyball, because they enjoy doing it. Three of the five users mention that developing the skills and improving the performance contribute to this. It is uncommon that technical applications are used within the practices, only occasionally videorecording is used. Nevertheless, most users are satisfied with the feedback currently provided at practices by trainers. Overall, receiving feedback in an alternative way is new to the users.

9.2. Evaluation prototype

First, the functioning of the prototype during the user tests is discussed in this section. Then, the usability and comfort of the prototype are evaluated. The focus is on how the users experienced the prototype and their suggestions for improvements. The experience of the vibration is part of the feedback system and will be discussed separately in the section 9.3.

The prototype did not work perfectly during all user tests, which led to uneven experiences. In two tests only one sock was working, including the test discussed in chapter 7. From both tests, it is concluded that two working socks are necessary to stimulate a correct posture. However, the users still provided useful information in the interviews, which is included in the evaluation. Also twice, the prototype stopped working during the last exercise. These users still experienced the complete feedback for a long time. These last minutes of malfunctioning did not influence the experience and were neglected. In one user test, there were no issues with the prototype. The malfunctioning always occurred in the left sock. It was caused by a soldered connection between the vibration motor and the wire connecting it to the Arduino breaking down. The pressure exerted on this connection within the shoe was too much, especially while doing exercises. Using more solder and redesigning the hardware within the sock would solve this. The right sock could be an example since this sock did not once break down. The malfunctioning can result in uneven experiences between users. Especially, the users with only one functioning sock were not fully stimulated towards a correct posture. They could shift the weight correctly for one foot, but not for the other, which still results in an incorrect posture.

It differed for each user how much the weight had to be shifted to turn the vibration motor on and off. This has also caused uneven experiences. The term sensitivity is used to describe this. With a high sensitivity it is meant that the vibration turned off already when a little bit of weight was shifted to the forefeet, whereas low sensitivity would mean that a lot of weight had to be shifted to the forefeet to turn the vibration motor off. Differences in sensitivity are caused by the settings that are determined in the initializing phase. The values chosen in the software are based on how the users posed when asked to stand in an active posture with the weight shifted to the forefeet. There is not one exact correct posture, which was asked to perform. So the way users perform this posture is also an individual preference. Eventually, the users with a high sensitivity could easily trick the system in not providing the feedback when it might be necessary. The different sensitivities can influence the experiences on the correctness of the feedback, the number of moments the feedback is provided and the preferred frequency of the feedback. The vibration strength setting was equal throughout the user tests. The experience of the vibration could differ due to different exact placements on the foot and tightness of the shoe, but this is neglectable. Overall, the sensitivity of the prototype differed per user and could influence the experience of the feedback on correct appliance and frequency.

The prototype is comfortable to wear. The vibration motor, wires and other elements placed both inside and outside the shoe are not hindering or bothering. One user experienced a bit a stiff feeling in the shoe because of the wires. All users mentioned that it was clearly a prototype, which should still be developed to become a product. The wires and other technology should then be more integrated and less visible. Especially the battery should be smaller. Another suggestion for improvement is emphasizing the location of the sensors, so the user is more guided in how to wear the sock. Overall, the product should be further developed to be used in practices, but for a prototype it is comfortable and not hindering in any way.

The prototype consists of two socks, but the feedback system could also be integrated in a different type of wearable. The users would never buy a shoe with the system, because of the expected price. Whether it is an insole or a sock does not really matter. It is essential for a sock to be washable if used regularly in practices. On the other hand, the insole provides less freedom in the placement of the sensors and the vibration motor correctly on the feet. So, the sock is a good option for a final product, but an insole with the same functions would also be fine.

9.3. Evaluation feedback system

The evaluation of the feedback system concerns the experience with the vibrating feedback: how the vibration felt, what message the vibration conveyed and whether the vibrating feedback was provided at accurate moments. Also, the users have been asked how often they would prefer to receive the feedback.

The goal of feedback is clear with an introduction. In the initializing phase of the user test, the user was asked to stand straight, stand on the forefeet and keep the foot in the air. It was checked whether the vibration turned on and off correctly when switching postures. The users know that standing on the forefeet is important in many volleyball situations, because of their volleyball experience. Therefore, it was quickly deducted by all users that the vibration would mean that the weight should be shifted more to the forefeet. The purpose of the feedback also remained clear during the exercises. However, it is not sure whether the feedback would be understood correctly without a similar introduction.

The vibration is mainly perceived as a notification. The vibrating feedback is clearly noticeable during the exercises, without feeling obtrusive. In experiment 3 of the ideation phase, the location of the vibration motor is chosen to stimulate a movement towards the correct posture. The meaning of the vibration would be ‘do not stand on the heel’ and stimulate moving the heel up. This is not how the vibration is interpret. The users were aware that the vibration meant that their posture was incorrect, but did not act on it immediately by changing the posture. The interpretation of the feedback differed depending on experience in volleyball.

The experienced users can immediately process and interpret the vibrating feedback, whereas this is more difficult for less experienced users. The experienced users analyzed why the feedback was provided and thus why their posture was wrong. They were reminded to prevent this in similar situations. In general, having the weight shifted to the heels is more common when the ball is thrown behind the player or when a player is in a backward movement. With the feedback system this was also experienced and analyzed by these users and it actively reminded them to pay attention to the posture in these situations. The intermediate and novice users do not know what to do with the feedback directly. They are focused on the ball and other context. The vibration fades to the background and is not experienced as important. It was mentioned that it might take some learning time to correctly interpret the system and to act on it by changing the posture quickly. Overall, the feedback system does not immediately correct the posture. However, the experienced users still benefit from it by analyzing the feedback quickly. The less experienced users have more trouble doing so, but might be able to learn interpreting the system better and faster over time.

The feedback system might not be stimulating to directly change the posture, because of the context involved in volleyball or the feeling of the vibration. The moment of action is short in volleyball. Within this moment the attention mainly goes to other aspects than the feedback: the context. The context demands a large amount of cognitive load and leaves few space to interpret the vibration. The cognitive load needed to interpret the feedback system should thus be very low. This can be influenced by designing the system differently. The vibration can be more annoying or painful, so it will be more intuitively avoided. If the users fully want to avoid the vibration, they will immediately lift their heels if it is felt. The vibration could be more annoying if it is placed differently or if the strength is increased. It could also be tested whether a different message with a different placement would lower the cognitive load and stimulate a faster change in posture. For example, by placing the vibration on top of the forefeet and thus conveying a pulling message of ‘move your weight towards the vibration’. The cognitive load needed to process the current feedback is too high to provide a direct change in posture. By increasing the vibration strength or changing the location, the cognitive load needed to process the feedback might be decreased.

It is desired that the feedback is provided continuously, so every time the posture is incorrect. This is in contrast with the literature in which continuously feedback is discouraged since it does not stimulate long term learning. However, it is mentioned that the continuous feedback gives the feedback system an exclusive advantage over a trainer who cannot provide such feedback. To stimulate the learning, it can be considered to switch in using the feedback system between exercises and practices to avoid dependency. When using the feedback it could still be continuously and hopefully noticed that over time the amount of feedback from the system decreases. That would mean the posture is improving. The literature and experience do not match. Whereas the continuous feedback is experienced by users as an exclusive advantage, it is found in literature that continuous feedback is not suitable to stimulate learning in the long term.

9.4. Implementation prototype in volleyball

Based on the experiences with the prototype, the users are asked if such a system could be implemented in volleyball. They are asked whether, how and when they would use the system themselves. Also, the view on who could benefit from using the system is evaluated. Some suggestions have also been mentioned to improve the experience. These are discussed in chapter 10, in the recommendations section.

The feedback system can be used in volleyball practices. It is not desired to receive the feedback throughout the whole practice. Control over when to apply the system should rest with the user. Examples of when the users would turn the system on are during passing exercises and in exercises in which many people are in the field and game-like situations are simulated. The system should be easy to control, which can be achieved by integrating one easy on-off button. The placement of the button and the kind of button should be determined to fit the users.

It is expected that volleyball players with all levels and experiences can benefit from the feedback system. Good players can learn from the few situations in which their posture is incorrect, whereas beginning players can get an impression of how often this active posture is important. The sensitivity of the system could also be adapted for players with different levels. A beginning player can be stimulated to make a small shift to get a feeling of the goal, where an advanced player might benefit more from a stimulation towards a posture in which the heels are fully lifted of the ground. It can be interesting to adapt the feedback system for different experience and levels of users to make it interesting and beneficial for all volleyball players.

10. Conclusion

The report is concluded with a discussion, conclusion and recommendation. The discussion links the literature results to the evaluation. The similarities, differences and factors that were of influence on the results are critically discussed. The discussion leads to a final conclusion, in which the answer to the research question is stated. The final section of the report, involves multiple recommendations for further improvements of the prototype, more research and future implementations.

10.1. Discussion

An evaluation was done with five users. One goal of the user tests was to find out what users think of the prototype and how it might be improved. Next to that, the goal is to find out more about how haptic feedback can be applied to improve posture in sports. Both the prototype and haptic feedback have also been researched in the literature. Within the discussion, the literature and evaluation will be linked. Besides, aspects that might have an effect on the results will be mentioned.

Technology to provide feedback in volleyball, and specifically haptic feedback, is not commonly used at an average level. This can be deducted from both the literature and the evaluation. Users mentioned to rarely receive technological feedback and to never experience haptic feedback in their practices. Nevertheless, the first acquaintance with a haptic feedback system was immediately received well. The advantages of the continuity of the feedback and the feedback on a detailed movement within volleyball were mentioned by the users. Although many people are satisfied with the current feedback in practices, more feedback is welcome. The advantages of using technology to provide feedback mentioned in the evaluation were also stated in the introduction. It is good to see that the advantages of involving technology in sports are recognized by users.

The sensitivity of the feedback system differed in between users, which can cause different experiences on correctness of the system and frequency of feedback. Although in the ideation phase the sensors did show similar values for different body shapes, this was not true in the user tests. The wider variety in values during the user test can be caused by less stable placement of the sensors below the foot. There is some freedom in the placement of the sensors, because they are integrated into two socks, which are used for multiple foot sizes. It was checked whether all elements were placed more or less correctly, but it could have changed when putting on the shoe. The variability resulted in personal adaption of the software during the initializing, which has resulted in different sensitivity settings. With a high sensitivity, the user can manipulate the system in not providing feedback although it is needed. This can influence the experience of the prototype in how correctly the feedback is provided and how well the user performed. This could cause continuous feedback to be preferred since it can be easily manipulated. Also, the system could be trusted less because it is not sure whether feedback is provided correctly.

The current design of the feedback system does not stimulate to directly change the posture to a more active one. The vibration is clearly noticed, but more received as a notification than to motivate a direct change. The feedback system was designed to push the user towards a correct posture. The movement necessary to correct the posture is a relatively simple skill. In the evaluation, all users were aware of how to perform this movement without instruction. Therefore, the focus of the feedback system should be on learning the user to apply the active posture at the correct moments. This is done by notifying the user through a vibration when the posture is performed incorrectly. This way of looking at learning a motor skill is different than discussed mostly in the literature review. In the review, the focus was more on how to efficiently learn a new motor skill or to improve a motor skill. Therefore, the effects of design choices as discussed in the literature review do not always apply to this feedback system. This should be accounted for when comparing the literature with the evaluation. The literature was thus focused on stimulating a desired movement to learn this movement, whereas the movement is known and the focus should be on when to apply the movement and posture. Therefore, it may not be such a problem that the feedback is not immediately experienced as stimulating.

The advice on continuous feedback might be influenced by shifting the way the movement is looked upon. Part of the conclusion of the state-of-the-art chapter is to avoid using continuous feedback since continuous feedback can be unbeneficial for motor learning. The user could get dependent on the feedback and therefore not improve the skills in the long term. It is not researched whether continuous feedback is also unbeneficial if it is applied to learn when to apply a motor skill. Therefore, this conclusion from the state-of-the-art cannot directly be related to the feedback system. From the evaluation it could be concluded that continuous feedback is preferred and experienced as helpful to learn when to apply the active posture. Also, it is one of the exclusive advantages of using technology to provide feedback. Therefore, more research has to be done to determine the effect of continuous feedback on learning when to apply a certain movement or posture.

The choice for vibration to provide the feedback was good. The vibration was clearly felt and not experienced as obtrusive. It has probably been felt slightly different for different users due to the exact placement of the vibration motor on the foot and the tightness of the shoe. However, this difference is neglectable considering the evaluation in which the feeling of vibration appeared to be experienced similarly. Although the vibration was a good choice, it can contribute to the notifying message the prototype gives. By still using vibration, but designing the system differently, the cognitive load of the feedback might be lowered and stimulate a more direct change. Possibilities are increasing the vibration strength or changing the placement of the vibration motor, including a possible change in conveyed message. Whether changes to these aspects would indeed create a feedback system that stimulates a direct change, should be researched. The literature did not discuss a certain message or placement to lower the cognitive load. Also, it is not known how low the cognitive load of the feedback should be to get the desired result. Overall, it can be researched whether different designs of the feedback system using vibration would stimulate the shift towards an active posture more.

The experienced users can analyze the feedback faster and improve their performance more during the exercises than the intermediate and novice users. The cognitive load of doing the relatively simple exercises might be lower for experienced users since they have practiced these exercises for over ten years. This leaves more space in the brain to interpret the felt vibration. For less experienced users the context in an exercise probably takes more attention and a higher cognitive load is needed to process this. This results in less time and room in the brain to process the additional feedback from the system. It should be considered that the user tests are conducted with five users. More research is needed to determine the influence of the amount of experience on the interpretation of the feedback system.

10.2. Conclusion

In this graduation project the goal is to answer the research question: ‘How to design a haptic feedback system that stimulates volleyball players to keep their weight on their forefeet during play?’. Based on a literature review and some experiments, a prototype is designed that provides haptic, or more specifically vibrotactile, feedback. Through user tests this prototype is evaluated to find out if this feedback system is stimulating to keep the weight on the forefeet.

The feedback system integrated in the prototype provides a notification instead of a stimulating push when the posture is incorrect. The location of the vibration motor, low on the heel, is chosen to push the heel upwards; the user should be repelled by the vibration. This is not true and the vibration is perceived as a notification that the posture is incorrect and a reminder to prevent this incorrect posture in the future. Reasons for this are probably that the vibration is not annoying enough and the cognitive load needed to process the feedback quickly is too high. The moment of action within volleyball is very short and to process the whole context involved occupies the brain. More experienced volleyball players can process the information of the feedback faster and improve the performance more while using the feedback system than less experienced players. This is probably because the cognitive load of the exercises is lower for more experienced players, which leaves room to process the feedback and act on it. Therefore, in the current design the feedback system stimulates experienced users to improve their posture, whereas less experienced users need more time to interpret the system correctly. Even though, the feedback system does not push the user to the current movement, a notification could still result in a more active posture if analyzed well by the user.

The feedback system is evaluated to be useful within practices for everyone, even though the stimulation could be stronger. Users would apply the feedback in their practices. The type of feedback is different from the usual feedback at practices: haptic instead of visual or audial feedback, which results in new insights and a new way of learning. Other advantages of the system are the ability to provide continuous feedback and to provide feedback on a detailed aspect. Both advantages cannot be offered by a human trainer. Therefore, the feedback system is evaluated positively and looked upon as a useful addition to volleyball practices.

10.3. Recommendations

Considering the future of this project, there are some short term suggestions, but also some more time consuming and complex suggestions. First, improvements to the current prototype will be shortly discussed. Than some potential additions to the system will be elaborated. This is followed by experiments that might be interesting to do with an improved prototype and possible future implementations of the system.

There are a few essential and obvious improvements that need to be made to improve the prototype and develop it towards a product. These improvements have mostly been mentioned in the user tests. First of all, the battery should be smaller. Also, the controller can be smaller, for which options are already discussed in section 4.4. These two suggestion are related to the advice to integrate the technology more into the sock. Some visibility is fine, but it should look less fragile and more as a finished product. The sensors and vibration motor might stay the same to achieve this. The wires should be replaced by conductive wire, so they can be stitched into the fabric neatly. Some additional state-of-the-art research is needed to discover the possibilities. One more essential integration is an easy on-off button. The current on-off button was not the easiest and would be removed when using a different battery. A new option to turn the system on and off should be found. It could be good to integrate users in figuring out where the on-off button should be placed and what it should look like. Overall, the technology should be more included and integrated into the sock and an easy on-off button should be added to develop the prototype more towards a product.

Besides improving these aspects, the product should be reusable. Users will not buy new socks for each practice. Reusing socks after a practice is not common. The prototype is not washable and is thus not reusable in its current form. There are multiple options to achieve a reusable product. One option is to integrate the technology into an insole. An insole has the advantage that it does not need to be washed. However, the on-off button might be harder to integrate and the technology should still be sweat resistant. Another option is integrating technology which can be easily removed from the sock with some kind of ‘click on click off’ system. A third option would be using water resistant and washable elements. The market for washable wearables is rising, but there are still many challenges. Research should be done to figure out whether it would be feasible to produce such a product. A combinations of removable parts and washable technology could be useful to create a reusable socks with an integrated feedback system.

Another addition that can be discovered is how the data from the system can be gathered and made insightful. Trainers would recommend the system to their players, but only if the data would also be shared with them. This should be done in an insightful manner. A possibility is synchronizing the data with a video recording of the player. It can be further discussed with trainers what they would expect and what they want to know. Trainers might recommend the system to their players without an additional function to gather data, if they trust the feedback system from their own experience.

A feedback system with an alternative placement and strength of the vibration motor can be designed to find out whether this is more stimulating towards the correct posture. The current design of the feedback system does not stimulate an immediate change in posture. It is more perceived as a notification of an incorrect posture. Although, the current design could still be useful, it is interesting to discover whether different design choices regarding the vibrating feedback would result in a more intuitive and direct stimulation to shift the weight.

There is not much known yet about which haptic feedback strategies might work and which do not work, as deducted from literature. It is important to gain more insight in the effect of haptic feedback on long term motor learning. The performance of a user should not only improve while using the system, but also when the feedback is removed. To guarantee a learning effect with this feedback system, a more structured and statistic research is needed. The prototype can be used with different settings by multiple groups of users. Their experiences are still important, but it would be mainly about counting the amount of right and wrong postures during exercises with and without the system. Most important, a retention test should be included to check if improvements while using the system remain present if the feedback is removed. The effects of continuous feedback on this movement and the influence of the amount of volleyball experience of users should be included. Overall, the system should be evaluated through a systematic research on long term learning effects and the influence of the frequency and the user's volleyball experience hereon.

Suggesting that improvements have been made and the system is evaluated to be effective, implementations of the system in other sports can be discovered. The focus in this project has been on implementing the product in volleyball. However, there are more sports in which a similar posture is important. For example, tennis requires an athlete to have the weight shifted to the forefeet most of the time. Furthermore, the sensors and feedback mechanism might also be programmed differently to apply to other sports and postures. More vibration motors could also be integrated to make the product applicable to more situations. So, the feedback system could be integrated in and adapted to other sports.

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Appendices

A. Brochure and informed consent form

Brochure and Informed Consent - Keeping volleyball players on their toes: a haptic feedback design

This research is by the University of Twente in the context of a B.Sc. thesis for Creative Technology. The supervisors work in the HMI department.

Main researcher: Suzanne Mulder
Supervisors: Angelika Mader, Judith Weda

In sports it is important to receive feedback to learn or improve skills, but also to prevent injuries. Usually this feedback is given by a trainer or coach. However, there are other possibilities, like in haptics. Haptics focusses on (experience of) touch. In my B.Sc. thesis the focus is on the posture of volleyball players when they should be ready to go for the ball. In common practice it is learned to shift your weight to the forefeet, so you can easily move to the ball. It will be studied how haptic feedback could best be designed to stimulate this posture during volleyball play.

In order to stimulate volleyball players to keep their weight on the balls of their feet, I designed a prototype (worn as a sock) which senses the weight shift below the feet and which provides feedback through vibration motors. These motors will be located on top of your foot and the goal is to stimulate you to put the weight on your forefeet during volleyball exercises. You will be asked to wear the prototype. First the settings will be adapted to the current sensor values and you will experience the feedback. If you do not feel comfortable with the feedback or with performing exercising while receiving this feedback, you are free to quit the study. After this initial experience with the prototype you will be asked to perform some exercises with it. These exercises will be video recorded to be able to analyze your posture while using the prototype. After performing the exercises you will be interviewed about your experiences with the prototype. This interview will be voice recorded. You are free to add comments and details apart from the questions. Besides the data from sensors and actuators from the prototype will be gathered for analysis.

The prototype will not hurt you and is safe to wear while doing volleyball exercises. The feedback will be felt as a soft vibrating touch to your skin. If you nevertheless think wearing the prototype and performing exercises with it could be harmful to you in any way, please refrain from participating.

Participation is voluntary. You can withdraw at any time, without giving a reason. Your data will in that case be deleted.

Data

The data will be safely stored and processed according to AVG guidelines. Research data will be stored until the graduation project is over in the end of January.

The data will be analyzed for research purposes. The analysis will be published in the B.Sc. thesis. The results presented in any publications are fully anonymous. The video footage will only be used for analysis by the researcher. No images from the video will be used in the report. Citations might be reported from the interviews, but no personal data will be connected to it. If you change your mind later and you want your data to be removed, you can contact me.

More information

If you have questions about this research, you can contact Suzanne Mulder (s.h.mulder@student.utwente.nl).

If you want independent advice about participating in this research, or if you want to submit a complaint. You can contact Petri de Willigen, secretary of the Ethics Committee (tel. 053-489 2085, ethics-comm-ewi@utwente.nl). This is a committee of independent experts at the university, they available for questions or complaints regarding the research.

Research: Keep volleyball players on their toes: a haptic feedback design

Hereby I declare,

- ☐ That I'm fully informed about the research. The goal of the research and the method are clear, any questions I had after reading the explanatory text were answered.
- ☐ I understand that I can withdraw from the research, without giving a reason, at any time without consequence.
- ☐ I give permission for my participation in the research and for collecting and using the data as described above.

______________________	________________________________
Name Participant	Signature Participant

I have provided explanatory notes about the research. I declare myself willing to answer to the best of my ability any questions which may still arise about the research.

______________________	________________________________
Name Researcher	Signature Researcher

B. Experiment 1 and 2: Sensors tests

Date: November 26, 2020

Discussed in section 4.2.

In this test the initial sensors covered in non-conductive fabric are tested to analyze the values. First both sensor are tested by pressing on them, which shows the difference in the values between the two sensors. Than three users are asked to take in three body position and the values are written down. The three body position are:

1. Standing straight up with the weight divided equally over both feet
2. Standing straight on one leg
3. Standing on the forefeet with two legs

Initial test: pressing with the hand with different strengths.

The results of the initial test are shown in Table 2.

Pressure	Heel value	Ball value
Nothing	147	106
Light touch	125	99
Medium push	84	66
Hard push	69	42
Nothing	144	101

Table 2 Results pressing with the hand with different strengths

Note: It is not sure whether the pushes are at same strength for both sensors, since they are applied manually.

Test: sensors below a foot, under body pressure in three positions.

The results of the tests with sensors below the foot are shown in a table per user, see Table 3Table 4Table 5.

Body position	Heel value (H)	Ball value (B)	Division H/B
1	42	18	2,333
2	38	13	2.923
3	79	13	6.07
No pressure	100	54	1,85

Table 3 Results User 1 - Sensors below feet in multiple body positions

Body position	Heel value (H)	Ball value (B)	Division H/B
1	46	19	2.4
2	41	14	2.9
3	52	13	4
No pressure	103	55	1.8

Table 4 Results User 2 - Sensors below feet in multiple body positions

Body position	Heel value (H)	Ball value (B)	Division H/B
No pressure	154	117	1.3
1	43	20	2.15
2	38	19	2
3	103	13	7.9
No pressure	105	60	1.75

Table 5 Results User 3 - Sensors below feet in multiple body positions

It is noticed that the shift from being straight up and standing on the forefeet can best be read from the heel value. The differences are much bigger there. In this test, the sensors were not attached to a wearable yet. The user stand on them. The set-up as pictures in Figure 12 is used.

C. Experiment 3: Vibration on the foot

Date: November 26 and December 11, 2020

Discussed in section 4.3.

In this test the a vibration motor connected to an Arduino through a transistor powered by a laptop has been used to test the perception of the vibration on different location on the foot. The numbered locations can be found in Figure 18. It is very subjective how someone perceives the vibration and what comes to mind. Therefore, it has been described in short descriptions. For person 2, some location and the intuitiveness were not tested. This data cannot be connected to the data in appendix A, since different persons have volunteered. The participants noted that the intuitiveness was hard to judge, but tried their best to imagine the use of the prototype in a situation with more context. All experiences of the three users can be found in Table 6.

Location	Person 1 (me)		Person 2		Person 3	
	Feeling of vibration	*Intuitive-ness*	*Feeling of vibration*	*Intuitive-ness*	*Feeling of vibration*	*Intuitive-ness*
1	Good	Good	Fine	X	Tickling	Ok
2	Good	Good	Fine	X	Very good	Ok
3	Good	Ok	Vibrates through up until toes	X	X	Little
4	Good	No	Not nice	X	Tickling	No
5	Good	No	Not very nice	X	Very tickling	No
6	Not so nice	No	Very annoying	X	No, annoying	No
7	Good	No	X	X	Fine	Ok
8	Good	No	X	X	Okay	No
9	Good	No	X	X	Not nice	No
10	Good	Ok	X	X	Very tickling	No
11	Good	Very good	X	x	Very good	Nice

Table 6 Experience of the vibration at multiple locations of three users

D. Planning User Test

Contents

Practical information

Location: Outside in a spacious area.

Participant: Volleyball player, older than 18, not injured, selected by me

Date: Week 1 and 2, 2021

Necessities:

- Video camera or mobile phone with a steady location, charged battery and enough memory.
- Volleyball
- Prototype
- Printed brochure and consent forms (2x) and this document
- Pen
- Audio recording device
- Laptop
- Mini-USB cable
- Spare battery

Initial steps and settings

0. Desinfect the hands, underarms, ball and other materials that will be used by the user.
1. Provide the participant with information. Let him or her read the brochure and sign the consent form, twice. One is to take home for the user. The other should be kept by the researcher.
2. Calibrate sensors: Write the values down from the serial monitor for both the left and the right foot sensed while standing straight, standing on the forefeet and having the foot in the air. Use table 1. Check whether the vibration turns on at correct moments. If necessary, use the values in table 1 to adapt the settings for when the feedback is provided if necessary.

Position // **Sensor**	**Heel sensor**		**Ball sensor**	
Foot	Left	Right	Left	Right
Standing straight up				
Standing on forefeet				
Foot in the air				

Table 7 Values read via Serial monitor

3. Experience feedback: Let the user experience the feedback, so he or she will not be surprised by the feeling. Possibly adapt the vibration strength settings if the vibration felt is too strong or too weak. Also check on this during the movement since the

environment might influence the experience of the strength. Write down the vibration strength.

Vibration strength = ……

2. Make sure prototype is working with the new settings.
3. Learn the participant how to turn the system on and off. This can be done by attaching and detaching the battery clip to the battery.
4. Ask if the participant feels comfortable with doing some exercises with the prototype. Tell the participant that remarks can always be made. This could also be done in the questionnaire.
5. Turn the video camera on, get the volleyball and start the exercises.

Exercises

General remarks:

- Explain the exercise clearly before performing.
- Check in every now and then if the feedback can still be felt.
- Insert unexpected pauses between throwing the ball to simulate the feeling in matches in which volleyballers tend to get lazier and to stand up straight when there is a pause in the action.

1. I throw the ball to the user.
   The user plays the ball with a passing technique back to me.
2. I switch between throwing, playing and hitting the ball, so the ball will arrive less constantly.
   The user plays the ball with a passing technique back to me. Standing on the forefeet is even more important since it is less clear what to expect.
3. I call the person or slap the ball and throw it right after this action.
   The user starts with the back towards the thrower. When I call or slap the ball, the user should turn and pass the ball that is already heading towards him.
4. The user starts on three meter distance from me.
   I give a sign that the user should start shuffling backwards and I throw the ball. This could be in the location the user is shuffling towards, but also a bit shorter since this provides a good check whether the weight is shifted correctly.
   The user passes the ball.
5. I switch randomly between throwing the ball short and deep/

The user passes the ball.

Questionnaire

General remarks:

- It is a semi-structured interview so the input of the interviewee is leading.
- The interview should be voice recorded
- Everything that comes to mind can be said. It is all focused on improving the prototype, so also negative experiences are valuable.

1. Questions about exercises
   How did you experience the level of the volleyball exercises?
      Why easy or hard?
   Were you satisfied with how you performed the exercises?
   Did you receive vibrating feedback from the prototype?
      When?
      How often?
   How did you experience the feedback?
   Did you feel like the feedback is provided at correct moments? So when you were not standing on the forefeet?
   Do you think the system provides intuitive feedback? So does it gives an intuitive sign to move towards the desired posture on the forefeet?
      If no, how could it be made more intuitive?

2. Overall
   What did you think of the feedback system?
   Would you use the feedback system?
      Yes → Why? In which situation (practices, matches)?
      No → Why? Would you consider using it in a different situation?
   When do you think this feedback is needed?
      Why?
   Who could benefit from using such a feedback system?
      Why?
   Why could the feedback system be useful?
      Does it trigger long term learning of the skill?

Is the wearable system comfortable?

Why is it comfortable or not?

What could be improved?

Is the vibrating feedback comfortable?

Why is it comfortable or not?

What could be improved?

What do you think of the implementation of the prototype in a sock?

Would you prefer the feedback system to be implemented in another wearable?

(Shoe, insole, flap)

What is your opinion on the frequency in which the feedback is provided?

Why?

Which location would you prefer to receive feedback to correct your posture to a more active posture on the forefeet?

Why?

When would you like to receive the feedback?

Every time that the posture is wrong, or in contrast, when it is correct. Or once in x minutes/seconds. A constant buzz when wrong, or on-off-on-off, vibration pattern.

3. Personal volleyball experience

How much volleyball experience do you have?

Which level do you play in the competition?

How often do or did you train per week?

Are you satisfied with the feedback you receive or received from your trainer and/or coach?

The amount of feedback? The kind of feedback? The consistency?

In your practices, do you ever use technical supplies to supplement, improve or support feedback given by a trainer or coach?

Do you think that more technical assistance should be used in volleyball?

What is your reason to play volleyball?

Hobby, improve, fun?

E. Arduino code

E.1. Arduino Uno

```
/*
  Name: Combined_for_prototype_uno
```

```
  Purpose: Read the value of a sensor and control a vibration motor
using
           an arduino uno.
  Date: 03-01-2021

  Velostat is a pressure sensitive material and is used to create a
  pressure sensor.

  Source filter: https://forum.arduino.cc/index.php?topic=545593.0
*/

const int heelsensorPin = A6;    //Input of heel can be read from pin
A6
const int ballssensorPin = A4;   //of balls from pin A4 (balls)
const int vibrationPin = 11;     //Vibration motor connected to PMW
pin 11

int sensorHeelValue = 0;        //Initialize sensorHeelValue
int filteredHeelValue = 0;      //Initialize filtered heel value

int sensorBallsValue = 0;       //Initialize sensorBallsValue
int filteredBallsValue = 0;     //Initialize filtered balls value

int vibrationStrength = 0;      //Initialize vibration strength
int setVibration = 150;         //Set the vibration strength (0-255)

void setup() {
  pinMode(heelsensorPin, INPUT);    // Declare the Velostat as input
  pinMode(ballssensorPin, INPUT);
  pinMode(vibrationPin, OUTPUT);    //Declare vibration motor as an
output

  Serial.begin(9600);               //Start Serial monitor
}

void loop() {
  sensorHeelValue = analogRead(heelsensorPin);  // Read the value from
the heel sensor
  filteredHeelValue = filter(sensorHeelValue);  // Filter the value
  Serial.print("Heel = ");
  Serial.println(filteredHeelValue);            // Write the value to
the Serial Monitor

  sensorBallsValue = analogRead(ballssensorPin); //Read the value from
the balls sensor
  filteredBallsValue = filter(sensorBallsValue); // Filter the value
  Serial.print("Balls = ");
  Serial.println(filteredBallsValue);            //Write the value to
the Serial Monitor


  if (filteredHeelValue < 30) {
    vibrationStrength = setVibration; //Turn the vibration motor on
    Serial.println("VM on");
  } else {
    vibrationStrength = 0;
    Serial.println("VM off");
  }
  analogWrite(vibrationPin, vibrationStrength);
}
```

```
/*
  Filters the analog value read from a sensor.

  @param: sensedValue, the value that is sensed via the sensorPin.
  @return: value, the value after filtering.
*/
int filter(int sensedValue) {
  int i;
  int value = 0;
  int numReadings = 10;

  //Loop through a set number of readings and add them
  for (i = 0; i < numReadings; i++) {
    value = value + sensedValue;      //Read light sensor data.
    delay(1);                         //1ms pause adds more stability
  }

  value = value / numReadings;       //Take an average of all the
readings.
  value = value / 4;                 //Scale to 8 bits (0 - 255).

  return value;
}
```

E.2. Adapted code for prototype

Two global variables are added to the Arduino program. These are set individually for each user in the initializing phase of the test. The ‘deltaValue’ is dependent on the difference between the values from the two sensors. It determines the sensitivity of the prototype, so with what amount of weight shift the vibration motor turns on or off. The ‘sensorHeelinAir’ is added to prevent the vibration motor turning on if the foot of the user is in the air. The value of the heelsensor is checked when the foot is in the air and a value just below that is chosen to put in the program.

```
int deltaValue = -15;   //Set delta to determine when the VM should
turn on
int sensorHeelinAir = 55;   //Set value of the sensor in the air
```

The if statement is adapted. The statements within the if statement have remained the same. First, it is checked whether the foot is in the air. Than the weight shift is checked. If the foot is not in the air and the weight is shifted too much to the heels, the vibration motor turns on, else it stays off.

```
if ((filteredHeelValue < sensorHeelinAir) && ((filteredBallsValue -
filteredHeelValue) > deltaValue)) {
    vibrationStrength = setVibration; //Turn the vibration motor on
    Serial.println("VM on");
  } else {
    vibrationStrength = 0;
    Serial.println("VM off");
  }
```

F. Summaries user tests

All user tests are conducted in Dutch, as this was preferred by the users.

User test 1

Date: December 30, 2020

Situation: Only the left sock was finished and tested in user test 1. The same interview and tests have been conducted as with all user tests. However, this test resulted in some important aspects that should be implemented directly before other user tests are done.

Notes: The battery came out of the battery pocket multiple times. The pocket was too low on the sock, so the shoe pushed the battery out of the pocket which probably caused the problem. This was temporarily fixed halfway the exercises using tape. The user noted that it felt like the length of the legs was uneven. This was probably caused by an extra sock on one foot, which was missing at the other. After putting an additional sock on the right foot as well, this feeling was gone.

Summary interview:

The battery did not stay in the pocket, especially if there was a lot of movement. Therefore, it was good that the exercises were quite static. The loose battery made the prototype feel fragile, which caused a feeling of limited freedom in moving. The wires also look fragile, but they are not felt or experienced as fragile when wearing the prototype. The Arduino nano is barely or not felt. The user expects that it is already much better if the battery moves less.

The performance in the exercises went less than expected, because the user was focusing on the working of the prototype on the one foot. This foot was therefore kept more static than the user would usually do. The user expects that the exercises would have gone better if the prototype was not worn.

The vibrating feedback was also felt when the foot was in the air. This limited the movement and increased the static posture, because even making a step was experienced as annoying and wrong.

The vibrating feedback is experienced as negative by the user. It gives a feeling of ‘I do something wrong’. It is felt very well. The user feels in through the whole feet. It starts around the heel, but is felt everywhere. The vibration does definitely not feel as a reward and the user tries to prevent it. It is not annoying, but also not fun.

The vibration has been felt during the exercises, but it was hard to determine whether it was vibrating because the foot was lifted or because the weight was shifted wrongly. Multiple times it was clearly because the posture was wrong.

Because of only having the feedback on one foot, the user noticed that it happened that the foot with feedback was in the correct position and posture, but all weight was put on the heel of the other foot, so the other foot was not correct. So it is very important to have the feedback on both feet.

Especially with balls that are thrown deeper, behind the player, the feedback was unexpectedly provided or when the user was in a backward movement. The user reasons that this makes sense because this is a position in which it is often forgotten to take the correct posture. This is an act of laziness, a player should go backward faster and then shift the weight forward when playing the ball. If the ball is thrown in front of the user, the weight is more automatically shifted to the forefeet.

The user thought the time span of the exercises is a reasonable time to have the feedback provided, but a whole practice would be annoying. The user would turn the system on in specific exercises in which it is appropriate. An easy on-off button would then be useful.

The system is useful in static passing exercises, but even more in game-like exercises and matches. To provide additional focus on the correct posture in exercises with many people and action. Considering a match, it would be nice to have the feedback during the rally, but during some rest after a rally. The feedback would be annoying and disturbing the rest. For matches this would be annoying. Maybe gathering the data is more interesting in these situations. That it can be analyzed afterwards.

The user thinks the feedback system is both interesting for experienced and less experienced volleyball players. More experienced players will probably be able to interpret and analyze the feedback better to really learn something from it. Beginning players will feel the feedback and know that they did something wrong, but might have a hard time to structurally improve their skills, because they do not understand why the posture is wrong or correct. They might need a better trainer on the side who can help with this interpretation part. Using the system in combination with a trainer is definitely good.

The feedback was provided at correct moments, when the posture was wrong, according to the user, except when the foot was in the air.

Intuitively the weight is shifted to the forefeet, because the feedback is annoying and not provided in that position.

The system is useful to gather more data in sports. Besides, it is a good help to a trainer who is not able to pay attention to everything.

The continuous frequency is good.

The user thinks it is more for prestation sports. In top sport, in general, more data is collected to assist the trainer. The idea of providing immediate feedback is nice. Amateur teams which mainly do it for fun, might not be happy using such a device. It also depends on the trainer, whether he or she sees extra value in the device.

The user would use the system as player. The defending skills can still improve a lot technically and the feedback system definitely has the potential to help. Feedback on taking the correct posture is often provided to the user. This device could help with more continuity in this feedback.

As a trainer the user would use the system if the data is also provided somewhere. If the data of the team can be gathered, focus points can be found for the practices.

The user hopes that the system stimulates long term learning and improves the skills without using it.

The system was quite comfortable, apart from the loose battery..

A right sock with the feedback system is desirable.

The prototype looks fragile, which makes pulling it on a bit scary, but when wearing it this feeling is gone.

The feedback system might also be useful for other sports.

It is good that the feedback is provided every time the posture is wrong. A reward in a good posture is unnecessary. Maybe a sound when the performance is good for five minutes.

The user has 18 years of experience in volleyball. Currently the user plays in the Dutch ‘promotieklasse’. The user has played ‘tweede divisie’. Neglecting corona, the user practices two times a week. The user likes the feedback normally provided by the trainer, but thinks more feedback is always appreciated.

The only technical supplies used in practices are recordings and analyzing these together, both used for technical skills and tactics in matches. The user thinks this is a very good addition to create more awareness within the player. It provides another look at it apart from hearing the feedback all the time.

The user plays volleyball because it is fun! In the beginning improving the skills was very important, this is still fun, but the level does not increase as much. Even though improving is less of importance, the user would still use the feedback system.

User test 2

Date: January 6, 2021

Situation: There are two socks finished and the suggestions from the first user test have been implemented. The system does not vibrate when the foot in in the air. Also the battery is better and higher attached.

<u>Notes</u>: When pulling the socks on, one is shifted slightly to the side. By notifying this, the user put the sock better on. Halfway the exercises, the right feedback system stopped working.

<u>Summary interview</u>:

The user has received feedback, especially at moments when the user was waiting for the ball to be thrown and if the user had to catch a short ball or a ball that comes very close to the body. In both situation the user also mentions that the weight in shifted to the heels which results in the feedback. The user also mentions that especially in the waiting situation the feedback has often given by a trainer in normal practices to have a more active posture with the weight shifted to the forefeet. When easy balls were thrown, there was no feedback and the user also felt that the right technique was used, but with balls that were slightly different than expected, the vibrating feedback was often provided.

The feedback was experienced as helpful. The user finally got what trainers always tell the user. But feeling it with this system, instead of hearing it, was very helpful. Also that the feedback is directly provided when the posture is wrong was helpful.

The user has the feeling that the feedback was provided at good moments, when the posture was wrong. This was not always when expected, but that is logical.

The user understanded the feedback quickly. The user notes that when you are not that experienced the feedback might not make sense. The one thing that is immediately known is that the heel should be lifted. The user also noticed trying to cheat on the system to not feel the vibration. The vibration was experienced as annoying and tried to be avoided, but the user thinks the vibration could even be a bit stronger. It was not comfortable to feel the vibration.

Maybe additional vibration on the forefeet pushes the foot even more to the correct posture.

The user likes the concept and says it is very interesting. However, another color would be preferred and more elaboration with less (visible) wires.

As a player, the continuous and direct feedback is very nice. As a trainer, it would be nice to receive the data, so the trainer is aware of the feedback system vibrating or not. This could be analyzed during or after the training. This way a trainer can get more insight.

The user would use the system. It helps in improving this skill, also without a trainer. It also works as a reminder that the posture should be different. However, the user would not use the system throughout the whole practice than it would get annoying.

The user thinks that volleyball players that have a lot of experience, but do not seem to improve this skill anymore, would benefit most from the system. For low experienced players it might also be interesting so they feel what they should do when. To really feel it instead of only seeing it.

If the system is used once in three weeks, it might stimulate long term learning most. Than the improvement can be seen from how much the system vibrates and hopefully this amount decreases. If the system starts vibrating more again, the system should be used more to improve the skill again.

Overall, the user sees potential in improving the skills with the help of the feedback system since in stimulates a posture which has potential to improve the overall volleyball skills. The better the volleyball skills, the more fun and the more motivating volleyball is.

The sock is comfortable, but there are many wires and a quite large battery. The eventual product could be more like a sports sock. It should be clearly shown how the sensors should be placed on the foot, so the user can be attention to this. The wires were not felt when wearing the prototype, but in the beginning there was a small fear of breaking them, mainly caused by seeing them when pulling the sock on. The user did not want to break the system.

In different exercises, different frequencies of feedback might be nice. In passing exercises once in the five times would be good, but in matches every time is better. It might depend on the user. The user would choose for continuous feedback.

An on-off button or situation knob on the sock is good, so the user can determine when the system does something. A remote control could be used, but this might get lost, so keeping it on the sock is easier.

The user has played volleyball for more than 10 years. Plays Dutch 'derde klasse', around the top 5 in the pool and is a trainer for three years. Normally the user practices two times a week and plays one match. The user is not very happy with the feedback provided by trainers. One can ask for feedback, but the level of trainers is not always that high technically. Concerning standing on the forefeet, it is also hard to provide useful feedback. It is not always visible and pretty personal.

One time video analyzing has been used, but no other technical supplies. The user thinks this can be applied more, especially after testing this relatively simple system. It depends also a lot on whether players really want to improve themselves. It is not useful if that is not the goal.

The user plays volleyball mainly because it is fun and stress relieving.

User test 3

Date: December 8, 2021

Situation: Same prototype as used in user test 2 before. The malfunctioning of the right sock has been fixed.

Notes: Halfway the exercises the left sock stopped providing feedback. Also the feedback system was not set very sensitive, as said by the user. The ground on which the exercises were done was also sloping which might have influenced the perception of the sensors.

Interview summary:

The level of the exercises was quite representative for the current level of the user. More complicated exercises might also be good to test the system in. However, this is not doable in a garden. Also, it might be hard to focus on the prototype, because there are many factors to focus on. The user tends to maximally focus on the ball which decreases the focus on the system. Maybe it is better to safe the data of the system, so it can be analyzed afterwards. The system might be more suitable for better volleyball players, because they can better focus on multiple aspects at the same time.

The vibration is felt, but not experienced as important. It feels more important to pass the ball correctly and ignore the vibration. The user thinks this is because of the low experience in volleyball.

Feedback has been received, mostly from the right sock. It could have been more sensitive. Now, the feedback was gone if the weight was slightly shifted to the forefeet.

The feedback was provided at correct moments. Sometimes this is hard to interpret especially when there are several short vibrations instead of one long vibration. The user has not learnt to fully stand on the forefeet enough in the normal practices yet. The system might be useful for beginners, because it is felt. Especially when the opponent serves and the user should be ready for the ball, the system would be useful.

The user knew what the feedback meant since it was told.

The user likes the idea of the feedback system and thinks it is useful. It could be integrated more subtle and nicer. If it is not too expensive, the user would use the system, especially if it is advised by the trainer.

The user thinks everyone could benefit from using the feedback system. Every player has moments in which the posture in not optimal. They could especially learn from the situations in which the posture is incorrect. Maybe the sensitivity could be different for different levels.

The prototype was a bit in an early stage. The technology that was in the back of the shoe resulted in a bit a stiff feeling. The wires were felt.

The vibration strength is actually very good. The user had to pay attention to analyze the vibration and know why it was there, but it can be clearly felt all the time. On the other hand, it is also not too overwhelming.

A sock has to be washed after every practice, so than the system can only be used once a week. An insole might be more practical.

The user likes the continuous feedback and would keep this the standard.
The user has about three weeks of volleyball experience, started this season with playing in a team in the Dutch 'vierde klasse'. Normally practice would be twice a week. The user is satisfied with the feedback provided at practices, but has only had two trainers to base this experience on. There are still many things to learn. No technical supplies have been used in practices. The user thinks this could be applied more, but how exactly is not clear. Videotaping might be an option. As a beginner in volleyball the progress goes one by one, so first the basics are fine. It is not necessary to improve constantly.
Volleyball is fun, because it is a team sport and the explosive character is nice. The user also wants to improve, which gives a feeling of fulfilment, but it is mainly fun!
The user likes the idea and mentions it could be on the market.

User test 4

Date: January 8, 2021
Situation: The left sock works again with initializing, but when moving to the garden to do the exercises, it stops working. After checking again, the left sock vibration motor seems to be broken. The problem seems to be in the hardware of the vibration motor. The test has been continued with only the right sock providing vibrating feedback.
Notes: The user prefers to keep the left foot in front and right foot in the back when passing. This results in the right foot being shifted forward most of the time, where the left foot might be a point of attention for the posture. However, the left vibration motor is not working. The experience is thus not optimal. Just like experienced before, two working sock are essential.
Interview summary:
The vibration is only felt on the right foot, but not very often. During shuffling it was felt sometimes. It was felt, but not very consciously. The user tended to get lost in the context and other sensations within the exercise, which kept the vibration on the background.
The vibration was not directly stimulating to shift the weight to the forefeet. It was present, but not present enough to directly stimulate that action. This might be better if the vibration would feel differently, a bit sharper. Now it felt a bit stump. It was more like a notifying vibration now.
The idea of the system is interesting. Many things can be seen with the eye and with other systems by doing measurements, but the best way to learn is by feeling feedback, directly triggering another posture.
The user would use the system if it improves the skills. Not in matches, but in the practices.

The user thinks it is useful for low experienced volleyball players to learn the right posture by feeling and not only hearing it from a trainer. Variation in ways of receiving feedback is good. But also for more experienced players, for whom small improvements can still be made, it could be useful.

The user thinks the system increases the consciousness of the posture. By using the feedback often, it will probably be done more automatically and thus improve the posture in the long term.

The sock was comfortable to wear. It just felt like a sock, nothing was different. In the beginning the vibration was a bit new, but the prototype was not uncomfortable.

It is good, at least for less experienced players, that the feedback is provided every time the posture is incorrect.

The vibration was felt very much at one point on the heel. This could be more throughout the whole heel. Also, a difference in strength depending on the amount the weight is shifted could be added.

The user plays volleyball for about two months now and a little bit in high school and practices two times a week. The feedback of trainers in current practices is good. It is personally adapted. Sometimes it might be nice to have some more feedback on details, but that seems hard for a whole team. For now the focus is on the basics, later on this can be added.

No technical supplies are used in practices. This could be done more. A feedback system like this could provide some extra feedback, especially on the details. This could definitely be beneficial.

Volleyball is fun, a team sports. Improving is also important, progress keeps it fun. The user likes the research and mentions that it might be beneficial to prevent injuries as well, such devices.

User test 5

Date: January 10, 2021

Situation: Both socks are working again.

Notes: The prototype has be repaired again. One wire of the vibration motor got loose and is soldered again. The vibration motor did still not provide full strength feedback. This was solved by replacing the battery, which was apparently almost empty. This also explained the weaker feedback user 3 got.

Interview summary:

The level of the exercises was fine, quite simple.

Feedback has been felt. If the user was focusing on the ball and passing the user did not focus on the feedback consciously. Within free playing the feedback was more present.

This might also be because the posture was more straight then. In passing exercises the user already tends to automatically shift the weight to the forefeet.

The feedback was present, but not obtrusive, also not directly provoking an action. In the initializing phase, the feedback already gets familiar.

The feedback is provided at correct moments.

The system works, but the process in which wrong and right are explained, make the user aware of it. Otherwise, it is not sure whether the system would have been understood correctly. It might not be present or annoying enough that it is immediately experienced as wrong. It also felt a bit random sometimes, maybe this was not the case, probably not, but there was such few structure that it did not feel reliable yet.

The system is a good idea and it can have potential. If the system would be turned on throughout a whole match or training, the user thinks it would be annoying. An on-off button would be good, better than creating a system which accurately measures when the user is in an exercise or not. A button placed on the pants or something would be fine.

The user would use the system in passing exercises, but also in combined exercises or practice matches. The combined exercises are important, because the user tends to have the wrong posture more often in this context than in plain passing exercises. Those are the moments that the user should be reminded of the posture.

The user thinks less experienced volleyball players would benefit most from the system since more experienced players already developed their own techniques, but this is just a guess. Beginning players often just stand in the field without a real posture and this might help to improve that.

The user thinks that if the player gets more used to the system and is better able to interpret the feedback of the system, when to ignore it and when not. The user thinks it also is a learning process to interpret the system well. By repetition it will be a more unconscious process to interpret the feedback and thus learn in the long term. It all goes very fast now. The context (ball, exercise) requires a lot of attention, so the focus is not on the system and the reflex is not present yet to immediately act on the feedback.

The wearable is comfortable. The battery can be more integrated, but that is logical.

If the user learns to interpret the system, the current way of providing feedback would work. Now it was not interpret fast enough yet.

A sock should be washed after each usage. Clicking out the system would be nice or it should be washable. An insole would also be fine if it is comfortable.

The user has played volleyball for four years. Started with no skills and now grown to playing in the Dutch ‘derde klasse’. Normally the user practices two times a week. The

user is happy and satisfied with the feedback from current trainers. Every year progress has been made so far. This curve will probably get more flattened someday.
No technical aids are used in practices. The user thinks this could be integrated more. Videotaping could already add a lot. Also, this system combined with a video would be nice. That a video can be watched in which it is also stated on which moments the feedback was given, so the posture was sensed as incorrect. It should be linked. Only numbers from the data would probably say nothing.
Volleyball is fun to do. Improving is important to keep it fun.