Bachelor’s Thesis

Feedback in Virtual Reality Rowing

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Abstract

Long-term injuries in rowers are an occurring issue in rowers, which can be attributed to a bad technique during the rowing stroke. Using Virtual Reality in combination with an ergometer can give rowers the opportunity to get feedback on their technique and posture. This system can support the coaches, who often have multiple ergometers to oversee during indoor training. The main focus of this research is on improving the feedback in the VR rowing environment through the data available from the ergometer.

This system has been through three previous iterations, and currently consists of the RP3 Dynamic ergometer combined with an HTC Vive. Research has shown that the power curve is an important feedback point of ergometer rowing. Although the VR environment is enjoyable to experience, it was initially meant to be used regularly, which is why the correct feedback would not only help new rowers to improve, but also gives intermediate level rowers the opportunity to improve with the help of statistics on their performance. Through a Java Platform and an external sever, a connection has been made between the ergometer and the VR system, creating the opportunity to use this available data in the VR experience. The force curve of the rower is currently shown in the environment, and this new system has been tested with beginning and intermediate level rowers.

The user test consisted of participants doing ten strokes before and after using the VR system, and a between-subject comparison was made, however, seeing as the system with the power curve had some systemic issues, the force curves of the participants were viewed more generally. Contrary to the previous research, the addition of the power curve to the system did not show a significant difference in the force curve of the rowers who used it and the rowers who didn't.

Despite this, there still lie a lot of exciting opportunities within the system, even more so now that the data from the ergometer is available. With the use of VR, new ways of giving feedback are possible, and the unused parts of the current systems might be brought back to improve the system in following iterations.

Acknowledgements

Here, I would like to thank a number of people without whom this research would not have been possible.

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I am honoured to have been a part of this project as it evolves into a better version at every iteration. I would gladly help out during the future iterations of the project, whether that be by assisting in explaining the workings of the system or being a ‘rubber duck.

Contents

1. Introduction

1.1. Background

The rowing machine, also called an ergometer, is an machine often used for training rowing indoors. Its usage extends to being used in general fitness as well, as the machine allows for a full-body workout.

In rowing, ergometers are mainly used for indoor training, when teammate availability or weather prevent outdoor rowing, or for rowing assessment [4, 5, 22]. The main focus indoors is often on increasing strength and fitness. In rowing clubs, a coach often is present to give feedback and corrects the rower on execution and posture. However, with the large number of rowers at the same time, it is hard to properly coach everyone [4, 22]. The ergometer itself can give feedback on for example the power curve, heart rate, distance, and stroke rate, but not on the position of the rower nor their technique. The latter is important, however, seeing as having a wrong rowing technique can cause long-term injuries [2]. Furthermore, compared to rowing outside on the water, rowing on an ergometer is less exciting, which can decrease motivation. This decrease in motivation may be a cause for the person to stay behind in their training compared to motivated individuals [18]. Getting accurate feedback could assist in regaining motivation and preventing long-term injuries.

FIGURE 1: RP3 METRICS INCLUDING POWER CURVE
SOURCE: [4]

The project itself builds on three previous iterations by other students, where the first iteration used trackers to indicate where and how the rower is positioned to give more accurate feedback [22]. The second iteration focused on giving multimodal feedback on posture and technique as well as adding elements to improve feedback on the different technical aspects of rowing [4]. The third iteration was centred around creating motivation through a non-player rower as well as gamification of the feedback [21]. Research done by [21] also has proven that the VR environment itself improves enjoyment through the environment while giving feedback on the rower's position and stroke movements [21].

The current system gives feedback inside the VR world on the pace, timing, speed, posture and handle height. The survey done in [21] shows that, when training on a rowing machine, rowers tend to also look frequently at the metrics of the machine, among which the force curve. A challenge that occurs herein is to improve the feedback currently given by accurately presenting the metrics of the ergometer as feedback within the VR environment, in a way that is accessible for a larger target group. Advances in technology, mainly VR, give more opportunities in ways to give feedback as well as making the system more affordable and convenient for the general audience as well as rowing clubs.

1.2. Goal

The goal of this project is to assess the given feedback of the current VR system, and to improve it through the additional element of a power curve. This is taking into account the feedback for both the technique as well as the posture of the rower in the different rowing phases – catch, drive, finish and recovery [28] , seeing as both are relevant to perform a stroke well and prevent injuries. This will allow novice rowers to learn the basics through posture, handle height and speed feedback, whereas more advanced rowers can make use of the power curve to improve their performance.

1.3. Research Questions

In order to reach the aforementioned goal, the following research questions can be stated:

Main Research Question:

- How can the feedback available through the RP3 be used to improve the feedback on rowing technique for a broader target group in an indoor VR rowing system?

Sub Questions:

- How can the application of VR in sports improve the workout experience of individuals?
- Which feedback aspects are relevant for novice rowers, compared to intermediate level rowers, to provide a better learning curve?
- How can the implementation of the power curve of a rowing machine in a VR environment improve feedback on technique in indoor rowing training?
- What impact does the Oculus Quest 2 have on the affordability, practicality, and experience of the VR rowing system?

The focus in these research questions is to improve motivation as well as giving accurate and relevant feedback while rowing in the VR environment.

1.4. Overview

In the beginning of this research paper, related work and projects relevant to the topic will be discussed. After this, interviews will cover the topic on how rowing coaches give feedback and what they advise to show in a VR environment. This is followed by a literature review which will answer the question on how the application of VR in sports improve the workout experience of individuals. This, in combination with the previously mentioned topics, will be integrated and described in the ideation process in order to indicate which elements to include or exclude in the final product. The design process, setup of the system and proceedings of the user tests will be discussed, as well as a conclusion drawn from them. This is followed by the conclusion, which will lead to an answer of the main research question. Lastly, limitations and opportunities for future research will be given.

2. State of the Art

In order to be able to assess the quality of the feedback given, prior knowledge is required on the rowing technique and common injuries in rowing, as well as the equipment used in indoor rowing and the different VR systems used in the context of this research.

2.1. Rowing Technique

When it comes to rowing, the rowing stroke generally consists of four different parts [28]. The first part of the stroke is the catch. This is the beginning of the stroke, where the rower sits up straight with folded legs and extended arms. Here, the oars are placed in the water. The second part is the drive. This is where the rower builds up power by extending the legs, still sitting straight with extended arms.
The third part, called the finish, is the end of the rowing stroke. This is where the rower has their legs entirely extended, with their back at an angle and the handle is pulled up to just below the ribs.
The recovery connects the rowing strokes; in reverse order, the rower moves back forward, with the handle beyond the knees. This is where the oars are out of the water.

This rowing stroke is displayed in figure 2. Most of the different steps of the rowing stroke have smaller steps within them, such as the order of moves to get from the recovery to the catch. Especially beginning rowers might have trouble to separate the different parts from one another, accidentally overlapping the different parts.

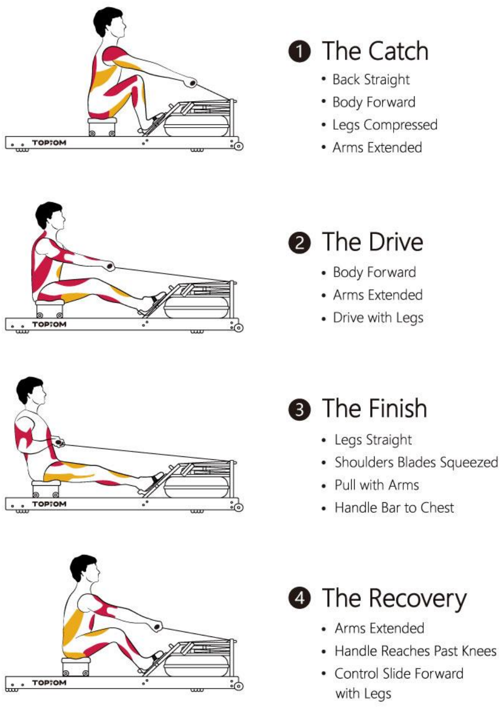

FIGURE 2: THE DIFFERENT POSES PER PHASE OF THE ROWING STROKE.
SOURCE: HTTPS://WWW.TOPIOM.COM/BLOG/INDOOR-ROWING-TECHNIQUE-101/

In rowing, there are some common technique mistakes, which often requires more attention, especially among novice rowers. While these errors might not seem bad in the beginning, it can be harmful in the long run and putting the rower at risk of injuring themselves, ranging from knees and arms to the lower back [30]. On the website of Concept 2, an overview of

some common mistakes is given [29].
During the catch, one common error is to reach too far forward or over compress (bend the legs too tight). This causes the leg drive to be less effective, and is an overall weak start of the rowing stroke due to the lost momentum. Furthermore, this can injure the knees and shins.
Another issue is over grip, where the rower grips the handle too tight. This can hurt the wrists and forearms.
As the catch progresses into the drive, rowers sometimes tend to bend the arms too early. The drive ought to be driven mainly by the legs instead of the arms.
During the finish, a common mistake is to lean back too far. This can injure the back muscles and weakens the finish of the stroke.
Bending the knees too early is an error made in the recovery, which causes them to become an obstacle for the handle; this is why the handle has to pass the knees before bending the knees. Lastly, the rower should not pull themselves back to the catch by using the foot straps.

One issue noted especially in indoor VR rowing is the turn of the handle at the catch, as this is often not as relevant on an ergometer, whilst it is an important part of the rowing technique.

2.2. **Power Curve**

The rowing stroke produces a watt plot or force curve, which describes the power in Watts or Newton generated during the stroke. This force curve is displayed on the ergometer screen. Although there is no 'perfect' force curve, the main objective is often to let is rise steeply, and to have a rounded shape. This stems from the way a force curve is built up. First, the legs put it a lot of power during the drive, supplying the most power at that time. This is closely followed by the power from the trunk. Lastly, at the end of the finish, the arms provide the most power to compensate for the decline in power from the legs and the trunk.

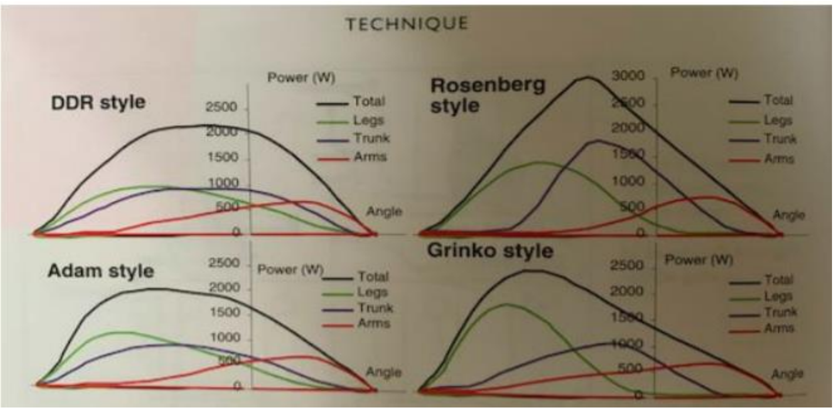

FIGURE 3: THE DIFFERENT STYLES IN ROWING AND THEIR BUILD UP.
SOURCE: [35]

According to Klesnev [35], as explained by Bowen, Dobay, Reardon and Thornton[36], there are four different styles of force curves among professionals. Normal rowers usually have a combination of these styles.
In DDR, as the legs extend during the drive, the trunk follows from being inclined to the front to inclined to the back at the end of the leg drive.
The Rosenberg style differs from this in that the trunk will remain inclined to the front for a longer time during the leg drive, creating a peak when the trunk moves back at the end (see figure 3).
The Adam style looks similar to the DDR style, differing in the longer leg drive and straighter

posture in the beginning of the drive.
Lastly, the Grinko style is mainly focused on the leg drive, after which the trunk moves backward at the end of the drive, making the curve skewed to the right.

2.3. Rowing Machine

In this project, the RP3 Dynamic rowing machine will be used. This rowing machine differs from the more common ergometer, the Concept2, in the sense that both the seat and the flywheel can move over the slidings. This creates a more realistic feel of rowing on water, as the rower is able to push the flywheel away during the drive.

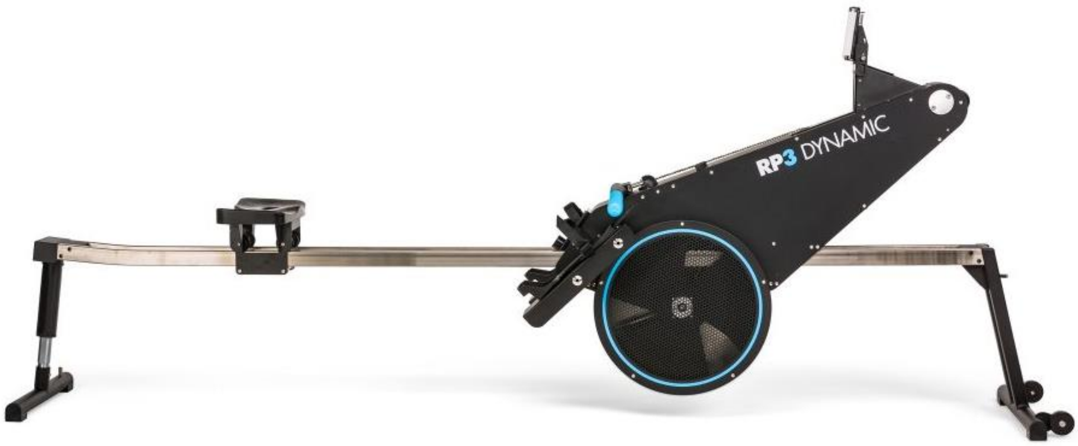

FIGURE 4: RP3 ERGOMETER. SOURCE: https://www.rp3rowing.com/

The RP3 already has software available to display and keep track of the data obtained during rowing. The RP3 can be connected to a phone or a computer, either through a wire or Bluetooth, or to other RP3s.
The metrics of the RP3, as shown in figure 5, displays interesting data such as the peak force and stroke rate, but it also compares the current force curve to the previous force curve made by the rower. The force curve should ideally be smooth and without disturbances, skewed to the right.

FIGURE 5: RP3 METRICS. SOURCE: HTTPS://WWW.ROWINGPERFORMANCE.COM/

2.4. VR system

2.4.1. HTC Vive

In order to create the intended level of presence, a VR system is used. Currently, the VR Rowing setup uses an HTC Vive.
The HTC Vive is a Virtual Reality Head Mounted Display (HMD) brought to the market in 2015 by HTC and Valve.

FIGURE 6: HTC VIVE. SOURCE: HTTPS://WWW.FLEXITRENT.COM/

The system consists of different parts. The tethered headset contains two OLED panels with each a 1080x1200 resolution. The dual microphones allow for 3D spatial audio with active noise cancellation, and the headset works with a 110 degree field of view as well as a refresh rate of 90Hz. The headset also contains an accelerometer, proximity sensor, gyroscope and a G-Sensor.

Two base stations track the headset and controllers. Also known as the Lighthouse tracking system, they can create a 360° virtual space. These stations emit infrared pulses to track the headset and controllers at 60 pulses per second.

The headset comes with two motion-tracking handheld controllers. Each controller has a battery span of about 6 hours. Each controller has a track pad, trigger and grip buttons. The Lighthouse system can track the controllers, and the controllers themselves have 24 infrared sensors which are used to determine their location relative to the headset.

The HTC Vive can also use trackers, which can be attached to physical objects and tracked with the Lighthouse system.

The system requires the SteamVR Tracking system to track the locations of the headset, controllers and trackers.

2.4.2. HTC Vive Pro

There is a notable difference between the 2015 HTC Vive and the 2018 HTC Vive Pro. First, the display resolution of the Pro has 78% more pixels, with two AMOLED 1440 x 1600 pixel resolution displays. Furthermore, instead of the one front-facing camera of the Vive, the Pro has two improved cameras, which can be used for motion tracking. The Vive also has audio as optional, whereas the Pro has standard integrated headphones.
The cable that connects the Pro to the computer also has been placed around the head along the band instead of over the head, which makes the cable less noticeable.

FIGURE 7: HTC VIVE PRO (LEFT) AND THE HTC VIVE (RIGHT). SOURCE: HTTPS://BLOG.BESTBUY.CA

Lastly, the Pro can make use of up to four base stations in a 10x10m area, and its multiplayer support has improved.

2.4.3. Oculus Quest 2

Another VR system to be considered is the Oculus Quest 2.

This system was released in 2020 by Oculus from Facebook. The system operates on Android, has built-in audio and can be connected through Bluetooth to either a smartphone or computer through the Oculus software.

FIGURE 8: OCULUS QUEST 2SOURCE: HTTPS://WWW.COOLBLUE.NL/

The system consists of a HMD and two controllers. The headset has two LCD screens at a 1832 x 1920 resolution. The system runs at a refresh rate of 90 Hz, and has an estimated 100-degree field of view. The input is given through 4 cameras which allow for 6DOF inside-out tracking. The headset has a battery capacity of two to three hours and has 64 GB storage.

The two controllers both have buttons, a thumbstick and a thumb rest sensor. They are 360° motion-tracking handheld controllers. Instead of the controllers, the user can also make use of the hand-tracking of the Oculus, which allows the user to select and scroll through items by pressing their thumb and index fingers together.

Lastly, the Oculus has recently launched the Air Link. Air Link allows the user to connect the Oculus Quest to the Oculus application running on a PC, as long as they are connected to the same strong Wi-Fi network. It is an improved version of the older Oculus application Virtual Desktop. The Oculus Quest can now also be connected to SteamVR on the PC.

2.4.4. Conclusion

The Oculus Quest gives lots of new opportunities for the project. First, because it is wireless, the ergometer no longer has to be close to the computer, and instead can be used in a larger area. This computer also will no longer need to be able to run the HTC Vive, which saves a lot of power. Although the Oculus Quest lacks the trackers of the HTC Vive, the hand-tracking opportunities and the two controllers make up for this. Another disadvantage is that, because it is wireless, the Oculus requires a strong Wi-Fi network, as the delay increases a lot when the internet speed drops. The Air Link does, however, allow the connection with SteamVR on the PC, which allows the project to run with the Oculus.

2.1. **Related Work**

2.1.1. Zwift

Zwift is a non-immersive indoor training app for indoor cycling and running. Zwift allows the user to connect their equipment to a Virtual Reality world where their speed is accurately represented. The system consists of a bike or treadmill which connects to an app, which is shown on a screen (see figure 9). The gear will measure the power output, which is translated to speed in-game. Zwift attempts to be as close to a real workout experience as possible, to the point that when the track goes uphill, the resistance on the gear will increase. It also gives the user an opportunity to train together with other people within a virtual world, and each can customise their own avatar.

FIGURE 9: THE ZWIFT BICYCLE SETUP. SOURCE: [26]

2.1.2. Holofit

The Holofit is an immersive workout app. The user wears a VR headset and can row through different environments. The environments are especially focussed on being immersive and increasing motivation through enjoyment. The app has five different game modes, which can be chosen depending on the workout the rower wants to do.
The rower, however, rows in the wrong direction here, which is interesting.
The app can connect to other rowers, so that it allows the user to row together with other community members. The system is compatible with smartphones, the Oculus Quest 1 and 2 and the HTC Vive Focus.
The app gives feedback on the average rowing speed, time, length, and Watt.

FIGURE 10: THE HOLOFIT ROWING SETUP. SOURCE: [27]

2.2. Interview with Experts

In order to get a better idea of the experiences of coaches, as well as their main focus points in giving feedback, three separate interviews were held with rowing coaches.

	I1	I2	I3
ROWING EXPERIENCE	5 years	9 years	5 years
COACHING EXPERIENCE	1 year	Some years of assisting	1.5 years

Ergometer vs. Outdoor

Usually, indoor rowing only occurs during winters or bad weather.

The advantage of rowing on an ergometer is that you can do some good power training. This is partly due to not having to take the balance of the boat into account, which allows you to draw out all your power. It is also possible to adjust your own power through the drag factor of the rowing machine. Indoor rowing makes you physically and mentally stronger from rowing on an ergometer; because it is so static, you can focus more on the rowing part. Another advantage of ergometer rowing is that you get to see data of the power you deliver, your heart rate, and speed. You or your coach can make the training more exciting by introducing some sprints, or you can put on some music or a movie.
Compared to the RP3, the Concept2 is more static; you move back and forth yourself, while in a real boat the boat itself also moves.

There are, however, also some disadvantages to ergometer rowing. Rowing on water is more enjoyable because you’re outside and surrounded by nature, whereas ergometer rowing is very one sided. Turning your blades and getting a good height so that the boat is balanced are not a part of ergometer rowing, as you only go back and forth without having to keep the balance of the boat. Overall, outdoor rowing is preferred because then you at least get somewhere. The advantage of rowing outside is that it is both more enjoyable and more technical. A rowing stroke on an RP3 is more true to the feeling of sitting in a real boat, however, in outdoor rowing you still have other people in the boat with whom you have to row together.

Feedback

Feedback during coaching depends on the technical focus for that training. Indoor, a lot of the feedback is focussed on the rower’s posture. When the coach observes a high split time, however, they will also give feedback that the rower should give more power. Furthermore, the coach has to observe 4 to 8 ergometers, which is a lot. It does, however, make it easier to stop one rower momentarily to correct them or give an example.

During outdoor rowing, the coach often gives an example on shore before cycling along with the rowers. Here, you can compare one rower’s position to that of the others, seeing as the rowers should be moving in a singular motion. Other feedback points are balance in the boat, the height of the handle, and observing the environment. However, depending on the coach, the feedback might also be more general for the entire boat.

When coaching beginners, one often observes them to blur the lines between the different phases of the rowing stroke. You can see this back in the power curve. For example, a spike will appear if you pull too much with your arms. These phases in the rowing stroke, as well as sitting up straight and keeping your core tense, are the first main focus in indoor rowing for beginners.

<u>Focus on metrics</u>

Lastly, according to the coaches, the main metrics of the ergometer more experienced rowers focus on are:

- Split time (time/500m)
- Time
- Power curve
- Watt generated
- Own points to be improved on

2.3. Survey by Annefie (2021)

During the previous iteration of the project, Annefie Tuinstra conducted a survey among rowers. The survey was filled in by 61 people, all of whom are rowers. The different types of rowers that filled in the survey are shown in figure 11. The participants of the survey were asked to fill in some questions about their background, e.g. their years of experience in rowing and their experience with the different types of ergometer, but also about ergometer rowing itself.

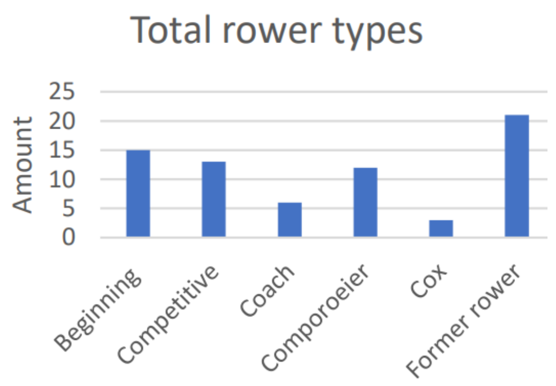

FIGURE 11: DIFFERENT ROWER TYPES THAT FILLED IN THE SURVEY. SOURCE: [21]

The survey had a lot of interesting outcomes on motivations, opinions and focus points in ergometer rowing. One interesting point that can be taken from this survey is the metrics that the rowers focus on during rowing. These are shown in figure 12, and shows that in descending order, rowers look most at:

- Current pace per 500 m
- Average pace per 500 m (Split time)
- Stroke rate
- Watt plot
- Elapsed / remaining distance
- Elapsed / remaining time

Of these different metrics, the second and third have been incorporated in the VR system already, although in a slightly different manner (speed in m/s). The watt plot, or power curve, was however not yet implemented, due to having no access to the data from the RP3.

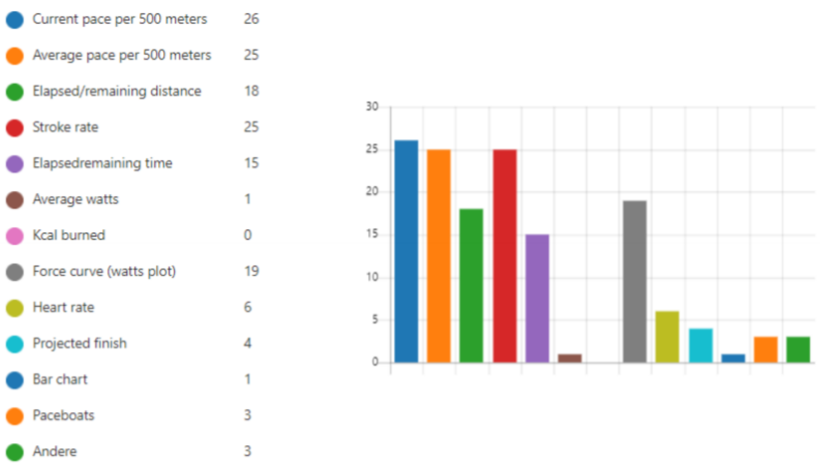

FIGURE 12: FOCUS POINTS OF ROWERS DURING ERGOMETER ROWING. SOURCE: [21]

2.4. The effects of VR in sports and rowing – a literature review

In order to get some insight in the relevance of using a VR system in the context of rowing and what it adds to the experience, a literature research was done on the topic of sports and Virtual Reality. The main focus here is the difference in experience adding a VR system gives. Another purpose of this literature research is to create some insight into why certain population groups have a high mental threshold to exercise in a fitness centre, and how VR-exergaming can help to lower this threshold. Thus, in this literature review, the research question addressed is how the application of VR in sports can improve the workout experience of individuals, and how this applies to novice rowers.

2.4.1. Introduction

Over the past decade, exergaming has become a more prevalent asset of the gaming industry and has many opportunities [20]. With exergaming, the combination of sports and technology is meant, wherein the technology specifically supports exercising [3, 23]. One opportunity in this field is the application of Virtual Reality (VR). Feedback from the VR system has proven to not only help prevent injuries, but also increase enjoyment and motivation to continue exercising and increases real-life performance [3, 6, 9, 10, 13, 15].

In the first part of the paper, the importance of a good mindset is stressed. The second part will discuss the different aspects of VR-exergaming. The third part will approach the effect of VR-exergaming on exercise and mental attitude, followed by an answer to the main research question of this paper. The last part will give a short overview of the limitations of this paper and opportunities for future research in the domain of VR-exergaming.

2.4.2. A good mindset

Especially in western countries, a large part of the middle-class regularly visits a fitness centre or gym for maintaining their physical health [1]. The opportunities to work out individually or in a group bring along good opportunities to stay fit. Especially in recent years, where the digital revolution has caused a more sedentary lifestyle for the majority of the population [16], engaging in regular workouts has become increasingly important.

However, there are several reasons that might deter people from working out in a fitness centre, despite needing the exercise. The main reasons for young people to quit are often having ‘professional obligations’ and ‘problems with time schedules'. For older people, health problems are a more heard reason to quit exercising [25]. Working out at the fitness centre, however, not only requires time, but also a good mindset. Enjoyment, motivation and self-determination are key in adhering to long-term training [9]. Feltz et al. [10] add to this that group achievement also increases motivation. In their research at NASA, where astronauts in the ISS lack social support to work out and fitness is considered monotonous, it was shown that engaging in group workouts are more effective than working out individually.

As Andreasson and Johansson [1] discovered, body image is also an important factor in motivation. According to them, the idea of the fitness centre or gym is often combined with the stereotype of a muscular man, and this can make people more hesitant to go themselves, especially if they have high body dissatisfaction. A negative body image can have both a positive and negative influence on motivation to exercise, as it can become a motivation to lose weight or gain muscle, but it can also cause shame and embarrassment to a degree where the person no longer wants to work out. Research by Haakstad et al. [11] has, however, proven that body image improves with exercise over time.

2.4.3. Different aspects of VR-exegaming

This is where VR-exergaming can help out. As shown in figure 10, exergames do not only have to be used in improving exercise-wise (optimisation), but can also be applied to the field of rehabilitation, injury prevention, or research. Furthermore, exergaming is by itself very inclusive, as it has a broad target population.

Feltz et al. [10] have shown with their SPACE research (Simulated Partners and Collaborative Exercise) that a motivational group feeling can be simulated by working out with a software-generated (SG) partner. The added value is that the difficulty of the exercise is controlled, and can be increased as the person progresses. This is important, as in order to be sustainable and remain entertaining, the gameplay needs to remain attractive and the exercise effectiveness needs to grow with the user [12].

There is a branch of exergaming that includes Virtual Reality in the experience, called VR-exergaming. To be more immersive than just a screen, the application of VR in exergames does not only have a focus on the visual aspect and giving visual feedback but also on auditory input [15]. Whether people intend to heavily use VR exergames or not depends on hedonic motivation, social influence and performance expectancy, with the latter having the strongest influence. The downside of VR systems, however, is that they are often considered

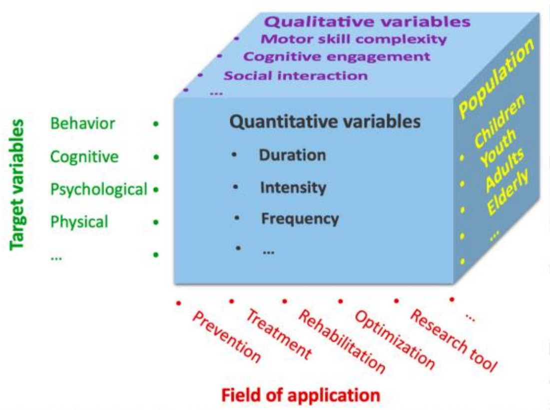

FIGURE 10: OVERVIEW OF DIFFERENT DIMENSIONS ASSOCIATED WITH EXERGAMING. SOURCE: [3]

expensive [8]. Furthermore, because of how immersive VR can be, there might be a fear of technology in people who have not experienced this earlier [6].

2.4.4. Effect of VR on exercise and mental attitude

The application of Virtual Reality to exergaming has advantages and disadvantages. The main advantage mentioned by the majority of sources was the increase in intrinsic motivation [6, 10, 12]. According to Farrow, Lutteroth, Rouse and Bilzon [9], this is caused by VR-exergaming inducing excitement and energy, which, in turn, leads to motivation. This theory was tested in relation to HIIT (High-Intensity Interval Training) and showed that, especially in the beginning phases of the training, VR can make a difference. The research concluded that, because of this motivation, people also tend to work harder in VR-exergaming. Through this increased motivation, exergaming improves health through increased physical activity [3] .

Mestre, Maïano, Dagonneau and Mercier [15] studied the psychological effects of VR on exercise more closely and confirmed that Virtual Reality has a 'dissociative' role during exercise. The sensory input that is given by the VR world generally distracts a person from muscle pain, increased breathing, etc. This does, however, depend on what type of sensory information given and exercise intensity. If the exercise is too intense, people tend to pay less attention to the game and more to keeping up with the pace of the exercise.

As shown in figure 11, exergaming in general also has downsides. The first is the increased screen time. Digitalization has become more and more integrated into our current society, thus increasing the time we sit behind a screen. Especially since the start of the COVID-19 pandemic, our daily interactions through screens has increased tremendously. By replacing traditional physical exercise with exergaming or VR-exergaming, this daily screen time will only increase, which has proven to be bad for mental health, lifestyles, but also can cause an increase of myopia (short-sightedness) in a larger part of the population [23]. Furthermore, there might be a prevalent fear of technology preventing the person from using exergaming or a generally negative attitude towards this type of technology.

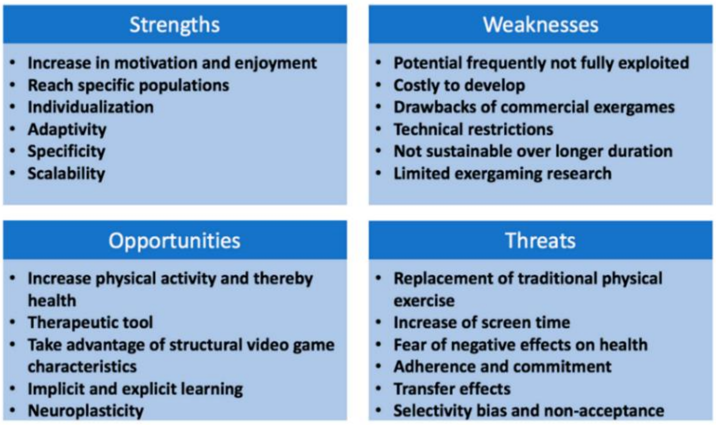

FIGURE 11: STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS ASSOCIATED WITH EXERGAMING IN CHILDREN AND ADOLESCENTS. SOURCE: [3]

2.4.5. Learning curve of novice rowers

The broadness of the field of exergaming can also be applied to rowing, and specifically ergometer rowing. This does not have to be solely among proficient rowers, as Černe, Kamnik and Munih [33] explain that ergometer rowing can also be found a lot outside of rowing clubs, and has become a sport of its own. However, the majority of this group has had little to no experience or instruction in rowing posture and technique. This group often has techniques that are different from the proper rowing technique, which can subsequently lead to long-term injuries. Figure 11 shows the average difference in posture between expert and non-expert rowers. Through research, Černe, Kamnik and Munih [33] found that, while expert rowers share a consistent technique that is similar at any stroke rate, the non-expert rowers have a technique that varies per stroke rate. The difference in experience can be seen in the handle height for example, where expert rowers show experience of rowing on water (see figure 13), where the oars have to be lifted and then placed back in the water, creating roughly an oval shape.

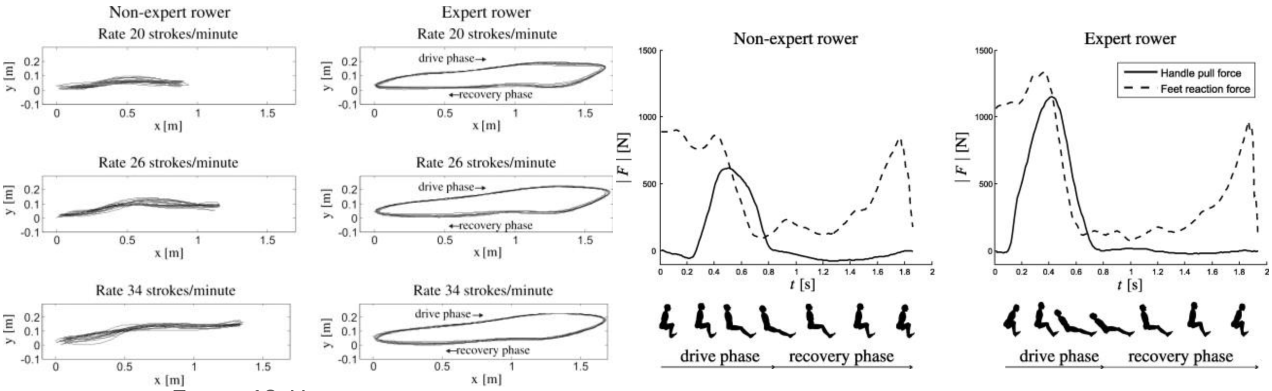

FIGURE 13: HANDLE HEIGHT AND POSTURE OF EXPERT AND NON-EXPERT ROWERS AT DIFFERENT STROKE RATES. SOURCE: [33]

According to Anderson and Campbell [32], a performer has the ability to acquire a skill through paying attention to a demonstration of that movement pattern or skill. This is called a 'perceptual blueprint', which gives the person a guideline for their later execution of actions. The more accurate this 'perceptual blueprint' is, the more accurate the movements are later on. This phenomenon can be used in regards to novice rowers, to accelerate their initial skill acquisition and, according to Anderson and Campbell, may also increase the participation rate of novice rowers. With the assistance of a coach, this process has the ability to increase the skill acquisition rate.

Soper and Hume [19] have researched the kinetics and kinematics of sculling and sweep rowing strokes. Their research related to ergometers showed that a difference in skill level of the rower can be seen in the force- and velocity-time profile they show. They claim that when a novice rower or intermediate level rower displays a profile similar to that of a professional rower, the rower is more likely to improve on their own performance.

VR makes way to a lot of opportunities in this field, too. Although following the example of professionals has proven to improve the rower's own technique, the majority of rowers, especially those outside the rowing clubs, doesn't have access to these examples, especially if they wish to tailor it to their own needs. VR can help in this aspect by giving these rowers the opportunity to get feedback on their technique, and compare it to that of professional rowers. This is just an example, seeing as there is a lot more possible within VR.

2.4.6. Conclusion

There are opportunities to help more individuals to become more confident in working out, using exergaming or VR-exergaming. Exergaming can be used in different areas, such as injury prevention and rehabilitation, but also optimization and research. Furthermore, it is generally accessible to most ages, and the software parameters (e.g. difficulty of the exercise) can be tailored to one's needs. Research done around (VR-)exergaming has shown that it has a noticeable positive impact on motivation, excitement and energy. Other researchers described VR-exergaming as putting one in a dissociative state, which distracts the person from fatigue and muscle soreness, thus helping the person to hold on longer. On the downside, there is, for example, screen time. With the digitalization happening in recent years, our screen time has gone up, which only will be increased if exergaming were to replace traditional physical exercise.

However, VR can also be used to improve the learning curve of novice rowers, both within and outside of rowing clubs. By following the example of a professional rower, and getting tailored feedback, novice rowers can be quicker to adopt a proper rowing technique.

In conclusion, (VR-)exergaming has a positive impact on motivation, and with the help of the dissociative state one reaches, it can help individuals with a negative body image or other insecurities to stay motivated and get exercise tailored to their needs.

3. Method

3.1. Creative technology Design Process

Over the different iterations of this project, the Creative Technology Design Process was used frequently. This design method was set up after the similar methods used during projects in the Creative Technology curriculum. This method can be used by students to come up with a wide range of concepts, take one or two of these concepts and improve them as it moves back and forth in a loop between the phases.

The method consists of four phases: the ideation phase, the specification phase, the realisation phase and the evaluation phase. While going through each of these phases, the project becomes more narrowed down.

During the *ideation phase*, the researcher maps out background information on the technology, takes stakeholder requirements and user needs into account, and creates the first concepts as well as mock-up prototypes (e.g. pen and paper prototypes). These concepts are based on interviews with the users or experts, observations, sketches, related work, etc.

When the concept is roughly mapped out, one proceeds to the *specification phase*. Note that there often is still some back-and-forth between the different phases, depending on certain outcomes, limitations or opportunities. In the specification phase, the concept(s) of the ideation phase are made more solid through several iterations of prototypes. These prototypes are evaluated, improved, built upon or even discarded, depending on the user experience.

When the adjusted and improved prototype is accepted by the user experience, the researcher moves on to the *realisation phase*. Here, the prototype will be turned into a product prototype by analysing the components required, and using these components to create a working version of the product.

Contrary to the previous two phases, the realisation phase is (nearly) linear instead of a loop, leading to the *evaluation phase*. Here, the product prototype is evaluated through reflection and user testing.

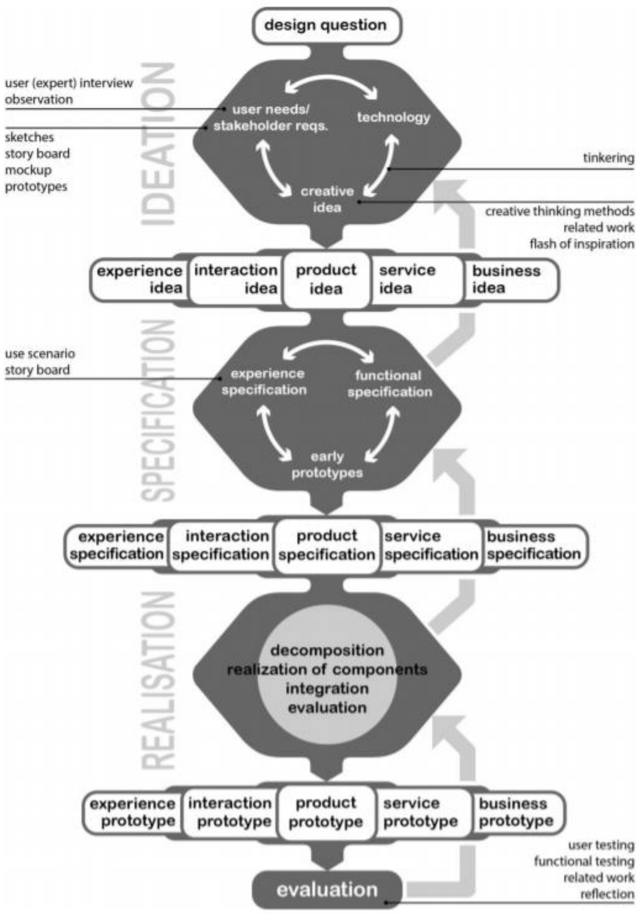

FIGURE 14: THE CREATIVE TECHNOLOGY DESIGN CYCLE. SOURCE: [31]

4. Setup

The current setup has been through a great many changes since the first concept. In Appendix A the manual can be found on how to boot and calibrate the current setup.

4.1. Rowing Machine

In this project, the RP3 Dynamic ergometer is used. This has two main reasons. First, in order to simulate rowing in a boat outdoors more accurately, the RP3 is more suited than the Concept2. As mentioned in section 2.2, while the Concept2 is more static, the RP3 is more dynamic, as the name already indicates. Instead of pushing your seat away from a static flywheel, the RP3 Dynamic has both a moving seat and a moving flywheel. This more accurately represents rowing in a boat, seeing as you push the boat away, so as to say, and not only yourself.
The second argument is that the RP3 Dynamic has an option to send its data either through a Bluetooth connection or through a wire. During the drive, it sends your force in Newton and your stroke length in meters. At the end of each drive, it sends your produced power in Watts, the relative peak force position, and generated energy in Joules. This data can either be used through an app on your phone, or, in this case, processed to be used in the VR system.

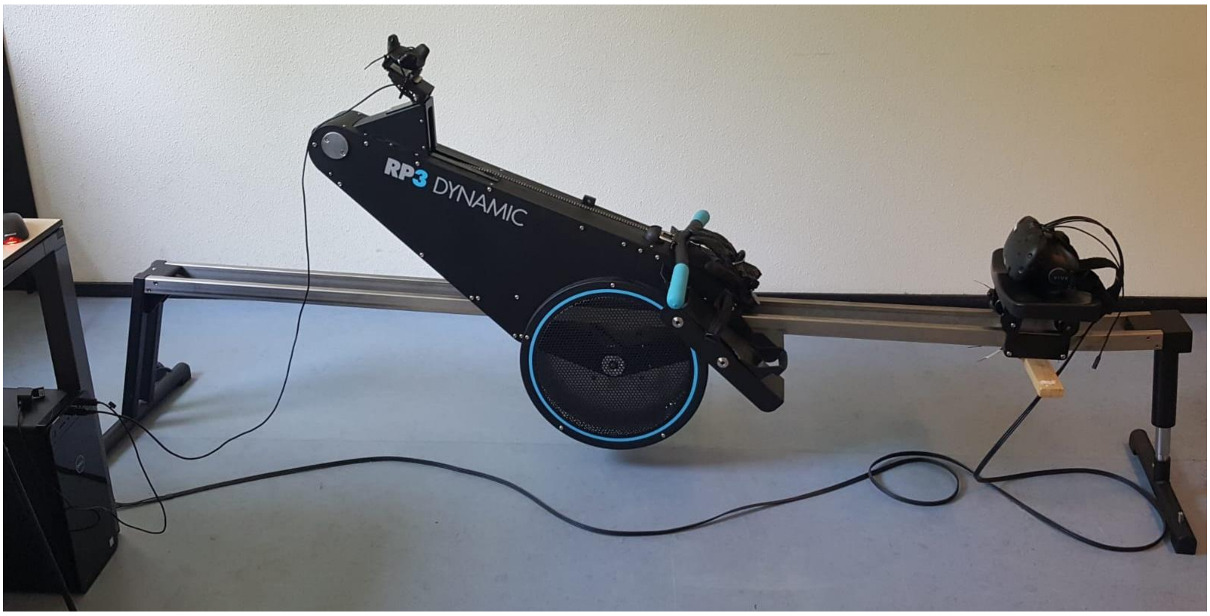

FIGURE 15: THE RP3 DYNAMIC ERGOMETER, CONNECTED TO THE COMPUTER THROUGH A WIRE.

4.2. HTC Vive

The current setup uses the HTC Vive in combination with three trackers. This is done to track the position of the flywheel, the seat, the head of the person (the HMD) and the handle (see figure X). The latter is tracked by a tracker on a glove, which the rower has to put on. The HTC Vive was selected for the project initially due to the common use, its highly accurate motion tracking abilities, the low latency of 22 ms, and the update rate of 120 Hz.

The HTC Vive setup also requires two base stations of the Lighthouse system to follow the trackers and the HMD. These trackers are placed in a 'corner' of the ergometer, meaning one at each end at an angle. This is to make sure that all the trackers are directly visible for the base stations.

The PC that the HTC Vive is connected to uses SteamVR, an application from Steam, to connect the Vive to the system.

FIGURE 16: THE HTC VIVE SETUP, WITH THREE TRACKERS AND ONE HMD.

5. Feedback Design

In this chapter, an overview of the design of the system will be given, as well as the manner of testing the newest version of this design. The previous design of the system will be shown, and the new additions will be explained in this context.

5.1. Previous Designs

In the previous designs, the different types of feedback have constantly developed and improved. Throughout the three previous iterations, more types of feedback have been implemented, with a focus on both the knowledge of performance (KoP) and the knowledge of results (KoR). Here, a brief overview will be given of the different types of feedback that were already present in the system at the start of this research.

Handle height

One noticeable type of feedback is the handle height. At the right side of the skiff, a dotted line is present, with small arrows along the line. This line represents the path the handle should follow during the rowing stroke. If the rower deviates too far from the line, a warning will be given in front of the rower, and the deviation will be shown shortly at the end of the rowing stroke.

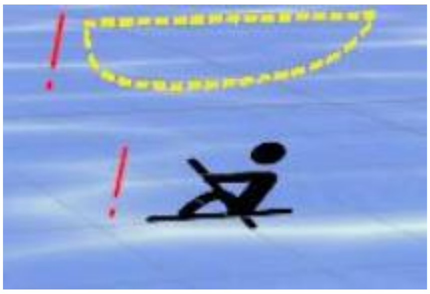

FIGURE 17: EXAMPLES OF THE WARNING ICONS.

This reflects the research of Černe, Kamnik and Munih [33], who have shown that handle height and the shape of the handle is significantly different between novice rowers and expert rowers. Taking the handle height into account is important for a number of reasons. First, if one were to row outdoors, the handles will have to be lowered and lifted to get the blades out of and into the water. Lowering the handle deep enough is important to prevent the blades from hitting the water, which in the best case slows the rower down, but in the worst case can cause the skiff to become unstable or turn. On an ergometer, one can argue, this issue is not present, especially if the person does not participate in outdoor rowing. However, on the ergometer, lowering the handle also has its use. First, it serves as a guide for the person when to begin bending the knees in the recovery. If the handle has not yet passed the knees, the person should not yet bend the knees, otherwise the handle will bump into them. Furthermore, it will prevent the chain of the ergometer from moving to the sides too much, which can cause the chain to hit the sides of the entrance of the flywheel.

Posture

Arguably one of the most important types of feedback given in the system currently is the feedback on the rower's posture. As mentioned in the introduction, injury prevention is one of the main objectives of this VR system. Posture is one of the main factors that can cause injuries in the lower back and arms, and is important to do well in order to make a good rowing stroke.

FIGURE 18: THE POSTURE CORRECTION AT THE FRONT OF THE SKIFF

Giving feedback on posture can be tricky, and this system makes use of the three trackers: one at the seat, one at the flywheel and one at the handle. The headset serves as the fourth tracker, which allow the system to estimate the body posture of the rower. In front of the rower, two figures are visible: a red one and a white one. The white figure represents the posture of the rower, while the red rower shows how the posture should be. The better the posture of the rower, the less visible these figures are. This is in accordance with coaching: if the person is doing well, they will not get feedback on their posture, whereas if they are slouching, moving too far back, etc, they will be given feedback. These figures are attached to the skiff.

Metrics
While the previous types of feedback were focused on knowledge of technique, there are also some metrics that work on the knowledge of performance. The metrics in this VR system include the stroke rate, speed at m/s, and the total distance.

FIGURE 19: THE THREE METRICS GIVEN ON SCREEN.

The stroke rate shows the number of strokes per minute. The average stroke rate of a rower during a workout lies between 24 and 30 strokes per minute[1]. The speed speaks for itself, although this can also be interpreted as the split time. The split time gives the rower their time per 500 meters. This split time system of time/500m is used most often in ergometer rowing. The numbers are generally white, but will turn red if the speed is on the low side, and green if the rower is putting in enough effort to row at a steady speed. Lastly, the distance is the distance between the rower and the opponent rower. If the rower slows down, the distance between them and their opponent will increase, and the numbers will turn red. If the rower is going at a faster speed than the opponent, the distance will decrease and the numbers will turn green instead. The combination of these three metrics gives the rower information about how fast they are rowing, whether they are rowing at a consistent speed and how far they are from their opponent rower. These metrics are attached to the headset view, making them in a fixed place on the rower's vision.

Boost
The boost is also a type of feedback focussed on knowledge of results. The boost contains three grey circles, increasing in size. If the rower manages to make a perfect rowing stroke, where there is no error in posture not in the handle height, one of the circles will turn green. If the rower makes three consecutive perfect rowing strokes. After three perfect strokes, the circles will turn back to grey, and around the screen, a green vignette will appear. The speed of the skiff will also temporarily be increased. This boost serves as both a motivator for the rower, as well as feedback for the rower that they are rowing a good rowing stroke.

FIGURE 20: THE BOOST WHEN THREE CONSECUTIVE PERFECT STROKES HAVE BEEN MADE

Opponent rower
To continue on this motivating factor, an opponent rower was placed in the scene as well. This rower's speed is dependable on the speed of the current rower, going slower when the current rower's speed is also low, and going faster if the rower's speed is also higher. The distance between the current rower and the opponent is also displayed on the screen, as explained above. If the rower makes a mistake, the opponent will get a short increase in speed. Whereas if the rower has a boost, this short increase in speed is larger than the increase in speed the opponent rower gains in case of a mistake. In this case, the rower is

[1] https://www.concept2.com/service/monitors/pm3/how-to-use/understanding-stroke-rate#:~:text=For%20rowing%2C%20a%20stroke%20rate,be%20between%2030%20and%2040

not able to catch up with the opponent through strength alone, but they also have to work on a proper technique.

5.2. New Design

In the context of this research, some small elements have been added to the system. Here, an oversight of the changes within the system, both visible and in script, will be given.

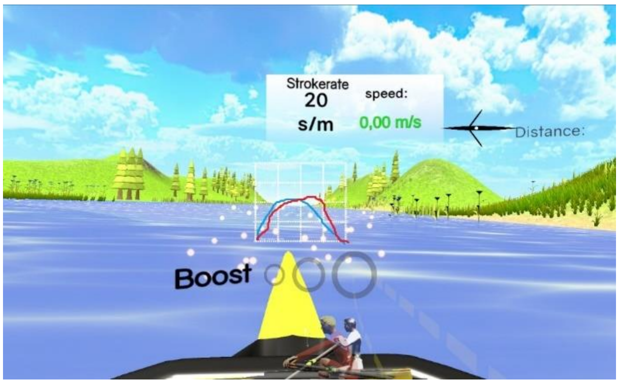

FIGURE 21: INCLUSION OF THE FORCE CURVE IN THE SCENERY.

5.2.1. Force curve graph

In the newest design of the system, the most noticeable difference is the graph in the screen. This graph shows a 'perfect' force curve as a reference, based on a normal distribution slightly skewed to the right, in the Adam style [35]. The force curve of the rower is displayed against it in red, to stand out. The data of this force curve is taken from the RP3. This curve will be refreshed after each stroke, to give the rower insight in what their force curve looks like and what parts they can improve on.

5.2.2. RP3 data

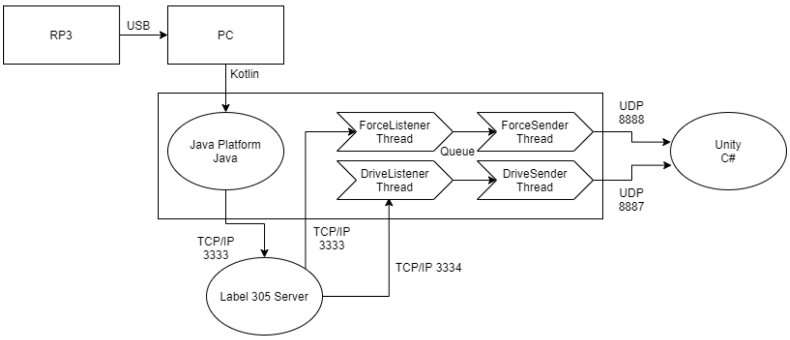

FIGURE 22: THE STEPS IN PROCESSING THE DATA FROM THE RP3.

The data used for the force curve has been processed from the RP3. The RP3 Dynamic gives the user access to data from the ergometer through either a Bluetooth connection or through a USB wire. The data is then usually processed through an app. In this case, the connection is still made through a wire connection between the RP3 and the computer.

Through a Java Platform, the data is taken from the USB port, and pre-processed. This pre-processed data is then sent to an external server from Label305, the company behind the RP3 Dynamic software. The connection is made through a TCP/IP connection on port 3333. The data is sent back to the Java Platform over two ports, 3333 and 3334. Port 3333 contains the stroke length in meters, as well as force in Newton. Port 3334 contains the power in Watts, the relative peak force position fraction, and energy in Joules. The server sends the data to the platform in strings, which are received by two separate threads. Threading was used for the reason that a lot of data needs to be processed simultaneously, and threading lightens the load on the computer cores.
Once the data is received, the strings are sent to separate 'Sender' threads through a Linked Blocking Queue. The 'Sender' threads send their data through an UDP connection to Unity

over an 8888 and 8887 port. Around 60 data points are sent per force curve, which are then used in the graph.

5.3. User Testing

In order to observe whether the implementation of the power curve had a significant effect on the performance of intermediate level rowers and the learning curve of beginning rowers, a user test was performed with these groups. The participants were filmed from two angles, and asked afterwards to fill in a survey about their experiences with the VR environment. The group consisted of nine participants. Two of these participants were beginning rowers, and two were former competitive rowers.

The test was set up to record the power curve data of the participants throughout the experiment in two different groups. The first group served as the control group, which did not see the power curve. The second group was the group That did get to see the power curve.

Due to persistent technical issues and the timeframe, the handle reacting to the power curve was omitted for the time being, making the inclusion of the power curve the main variable to test on.

Before the experiment, the participants were shown a short video on the proper rowing technique. This was done mainly because, as stated earlier, this machine does not serve to replace the coach, but instead to assist them. Under normal circumstances, a coach would be present to teach the novice rower the basics of the rowing stroke. Subsequently, they were informed about the different types of feedback rowers usually get, especially related to the ergometer. These were, for example, the split time, the power curve or handle height.

After these explanations, the participants were asked to put on the glove and row a couple of strokes to get used to the machine. This counted for both the rowers and the non-rowers, seeing as the non-rowers had to get used to performing a rowing stroke, and the rowers had to get used to the dynamic RP3 in contrast to the Concept 2.

Then the participant was asked to row 10 strokes: these strokes were recorded for reference material. In order to record these strokes, the virtual environment was already started before these 10 strokes. Following this, the participants could put on the headset. They were given time to adjust their headset if necessary, until the image was clear, and whether the bindings of the HTC Vive were correct, as this would sometimes present itself as a pop up in the system, blocking the view.

There were two types of environments to be tested per group (rowing and non-rowing). These variables were tested randomly per participant. This created the following variables:

- System with power curve (P)
- System without power curve (W)

Non-rowers	Intermediate level rowers
P	P
W	W

If the headset was fine, the participants were told to row for 5 minutes. During these 5 minutes, note was made of any observations the participants made while rowing. After these five minutes, the participants were given a short moment to calm down after the exercise, and were then asked to row ten finalizing strokes without the headset, to measure the power data.

Following this rowing part, the participants were asked to fill in a survey about their previous experience with rowing, as well as their enjoyment and motivation.

A part of this survey makes use of the Intrinsic Motivation Inventory (IMI). IMI was created by Ryan and Deci in 2000, and serves to measure and assess the experience of a participant, which by definition is subjective. IMI makes use of several subscales that assess different parts of intrinsic motivation. These subscales can be used and slightly modified to suit the researcher's own questionnaire[2].

5.4. Observations

During the preparation phase, the non-rowers especially appeared to require some getting used to the rowing stroke, as well as the fact that both the seat and the flywheel move, which presented itself in some difficulty to get seated and adjust the foot straps. The order and manner in which to execute the rowing stroke did also pose some issues, as ti cannot entirely be learned through the video, but also requires at least some experience of the participant rowing themselves. Some had to be given some extra instructions so as to not hurt themselves while rowing. Although the more experienced rowers did not have extensive experience with the RP3, they did get used to the system quicker.
The difference between the rowers and non-rowers was also noticeable. Whereas the rowers had no problem to do the initial 'familiarizing; strokes and ten rowing strokes, the non-rowers appeared hesitant, and showed confusion at times on how to make a proper rowing stroke. Some participants tried different ways of rowing initially, whereas some immediately assumed a steady pattern.

<u>Focus</u>

When the participants put on the headset and began rowing, the initial focus was on rowing, and looking at the different metrics. It took some participants a while to notice there was another rower, and one participant even did not notice the handle path on their right. For a short while in the beginning, the participants might look around from time to time, but after several strokes, the main focus shifted to rowing entirely. In the five minutes, the focus of the non-rower participants shifted quite a bit. Often, when a mistake was made and the error icon appeared, the focus shifted to the error.

The opponent rower showed to be one of the main motivators in the participants that did notice them, however. While the rowers moved at a steady, slightly higher pace than the opponent, the non-rowers were either too focused on rowing or the metrics, or they wanted to catch up with the opponent as fast as possible. The latter often resulted in ignoring the mistakes in technique. Two non-rowers also expressed their desire to be as fast as possible.

<u>Lag</u>

Unfortunately, whether this be to a systemic error or due to the large amount of data to be processed by Unity, the system containing the power curve had a major lag at time. At some points, the system even froze for several seconds. The participants noted this as 'night mode'. Although two of the participants seemed to enjoy the occasional shifts to this 'night

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[2] https://selfdeterminationtheory.org/intrinsic-motivation-inventory/

mode', which was really a home screen of the HTC Vive, the other participants got confused by the shift from the moving environment to the still, bodyless home screen while rowing. One participant even gave up on rowing momentarily due to the frequent shifting during that test.

6. Discussion

Here, the results of the user tests as well as the interviews and background research will be displayed.

6.1. Findings

6.1.1. User Tests

As explained in part 5.3, a user test was performed on 9 participants. Due to the limited number of intermediate level rowers, there was not really a possibility to compare the rowers to the non-rowers. Seeing as trying to compare the two groups would statistically be invalid, the research instead regards the entire group of participants equally in regards to their force curves, as shown below.

The ten strokes before the five minutes of rowing in the VR system were compared to the ten rowing strokes afterwards. The average of the rowing strokes before and after were taken per participant, and placed in a graph as shown in figure 23 and 24. The curves observed in the graphs are the force created in Newton. This is slightly different from the power curve observed in an ergometer, which is in Watts and uses the following formula[3]:

Power = (Force * Distance) / Time

However, seeing as the data from the RP3 is sent at the same intervals in time and distance per stroke, the shape of the curve does not differ.

There are some differences to be observed between the force curves before and after using the VR system. The first difference that can be seen in the graphs is at the beginning of the leg drive. Before using the VR system, this start was often unstable (2), after which the peak was quickly reached. This can be seen in the frequent rise and drop of the force. In the force curves produced afterwards, these initial instabilities have disappeared or smoothened out, making the curve rounder. These instabilities in the beginning of a force curve appear between the catch and the start of the leg drive, meaning that the participant needs to focus on making a smoother transition from the catch to the drive.

Next, we can observe that the first force curves contain some curves that have two 'bumps' (3 and 4). Bumps indicate that there is power lost during the rowing stroke. These bumps can be caused when one muscle group takes over too late from the other, or when the rower forcefully pulls the handle back at the end of the rowing stroke, resulting in a sudden second peak in the second part of the power curve. In this case, the rower has to work on the transition from the leg drive to the trunk to the arms, as they are currently losing power in this transition.

The flatness of some of the curves can be attributed to the participant not being used to rowing or the RP3 Dynamic, seeing as it indicates a lack of power throughout the stroke.

The drop at the catch (1) is also called the 'slip', where during outdoor rowing it means that the rower experiences a decrease in force suddenly due to the blade catching the water. The water causes a negative breaking force, which causes the sudden dip in force[4]. In ergometer rowing, this indicates often that the individual is pulling the handle at the catch.

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[3] https://www.crossfitinvictus.com/blog/concept2-force-curve-graph/
[4] http://biorow.com/index.php?route=information/news/news&news_id=29

Another thing that can be noticed is that the peak of some curves in the second figure have shifted to the right (5). This shows that the participant needs to get more power from the leg drive, as the main power now comes from the torso and the arms.

No significant difference can be observed between the users who had the system with the power curve (p1, p5) and the other participants.

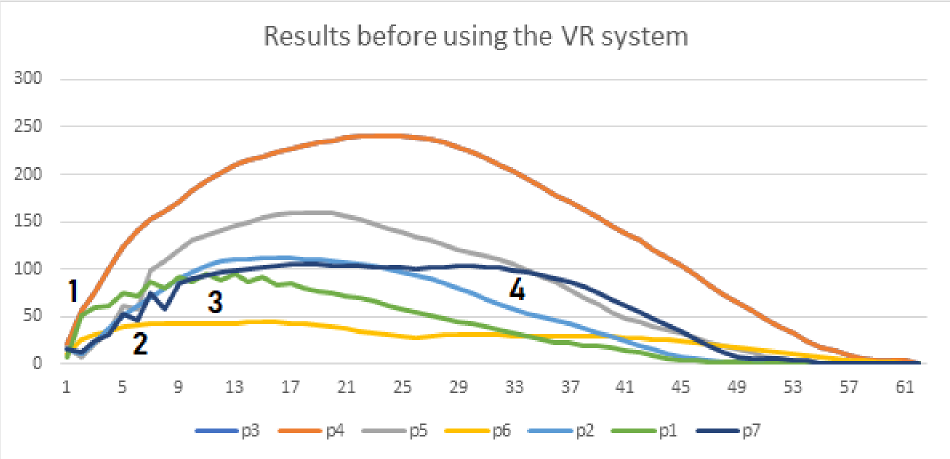

FIGURE 23: GRAPH OF THE AVERAGE ROWING STROKE PER PARTICIPANT BEFORE USING THE VR SYSTEM.

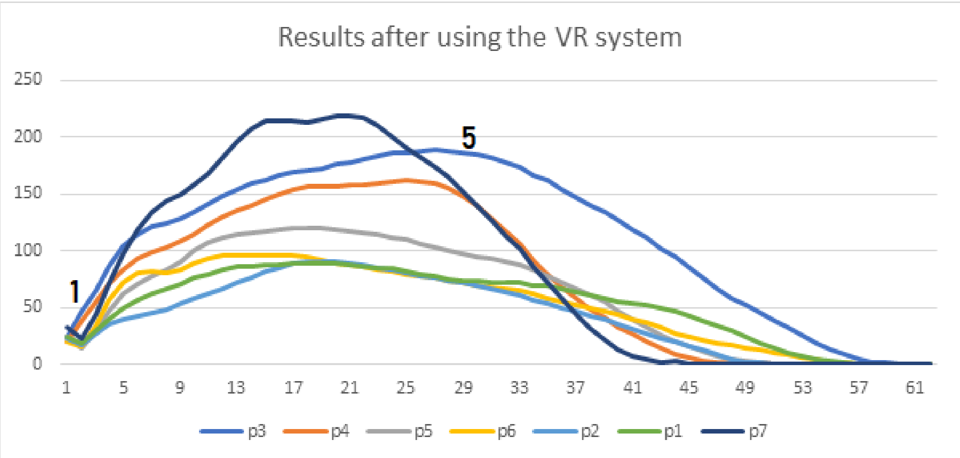

FIGURE 24: GRAPH OF THE AVERAGE ROWING STROKE PER PARTICIPANT AFTER USING THE VR SYSTEM.

In order to see whether there was a significant difference between the curves before the VR system and the curves after it, the statistics of the average graphs were looked at. These statistics can be seen in table 1. In C4, C6 and C7, the mean has increased, whereas in the other cases it has decreased. With the exception of C4 and C7, the standard deviation of the graphs have been decreased as well.

From the kurtosis we can observe that the majority of the graphs have a kurtosis of less than -1, which means that they can be considered non-normal. Only the before graph of C4 and the after graph of C6 are an exception to this. The curves are not substantially skewed, seeing as the skewness of the graphs is between -1 and +1.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
b1	62	.0000000	241.0075000	140.8575276	83.14253725	-.385	.304	-1.307	.599
b2	62	.0000000	241.0075184	140.8575279	83.14253545	-.385	.304	-1.307	.599
b3	62	.0000000	159.7194706	76.26634494	58.79866487	.031	.304	-1.608	.599
b4	62	.0000000	43.4965900	26.94894077	12.96347952	-.601	.304	-.575	.599
b5	62	.0000000	111.4856000	50.50056542	43.08089284	.154	.304	-1.607	.599
b6	62	.0000000	95.2454000	38.70223403	34.19471383	.239	.304	-1.529	.599
b7	62	.0000000	105.2332000	60.18304827	41.88519637	-.345	.304	-1.619	.599
a1	62	.0000000	189.0000000	111.9032258	64.88368147	-.482	.304	-1.219	.599
a2	62	.0000000	161.9055654	75.06564455	63.83345271	.065	.304	-1.677	.599
a3	62	.0000000	119.9717400	60.16661102	46.28088335	-.118	.304	-1.642	.599
a4	62	.0000000	96.6936720	51.35036100	34.39903473	-.221	.304	-1.485	.599
a5	62	.0000000	90.9773000	42.73476245	32.26182381	-.021	.304	-1.445	.599
a6	62	.0000000	89.5045900	52.48748844	30.94691078	-.523	.304	-1.153	.599
a7	62	.0000000	219.3042000	89.55350521	85.93943744	.277	.304	-1.611	.599
Valid N (listwise)	62								

TABLE 1: OVERVIEW OF THE STATISTICS OF THE AVERAGE FORCE CURVES PER PARTICIPANT BEFORE(B) AND AFTER(A)

This can be further supported by the Shapiro-Wilk test as seen in table 2. The significance here is .000 for each graph, indicating a small chance that the data was taken from a normal distribution. Therefore we can safely assume that at an a=0.05, these graphs are not normally distributed.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
b1	.124	62	.019	.894	62	.000
b2	.124	62	.019	.894	62	.000
b3	.126	62	.016	.882	62	.000
b4	.140	62	.004	.911	62	.000
b5	.147	62	.002	.860	62	.000
b6	.153	62	.001	.871	62	.000
b7	.193	62	.000	.819	62	.000
a1	.129	62	.012	.888	62	.000
a2	.158	62	.001	.846	62	.000
a3	.140	62	.004	.859	62	.000
a4	.124	62	.019	.894	62	.000
a5	.126	62	.016	.901	62	.000
a6	.140	62	.004	.885	62	.000
a7	.187	62	.000	.830	62	.000

a. Lilliefors Significance Correction

TABLE 2: TESTS OF NORMALITY PER GRAPH

With the help of the skewness and kurtosis, we can however make assumptions on how close a graph is to being a normal distribution. The kurtosis or 'tail-heaviness' of a normal distribution is 3. The skewness or symmetry of a normal distribution lies around 0. If we assume that a perfect rowing stroke is either normally distributed or skewed to the right, we are able to estimate which curve is closest to a normal distribution. However, this depends on what we take as the definition of a perfect power curve; is this a normally distributed curve related to the DDR style mentioned by Klesnev [35], one of the other rowing style curves, or a combination?

6.1.2. Survey

After the rowing, the participants were asked to fill in a survey about their experiences with the system. Of the nine participants, two were beginning rowers, and two former competitive rowers. The other five were non-rowers. Considering the low number of participants in the user study, the

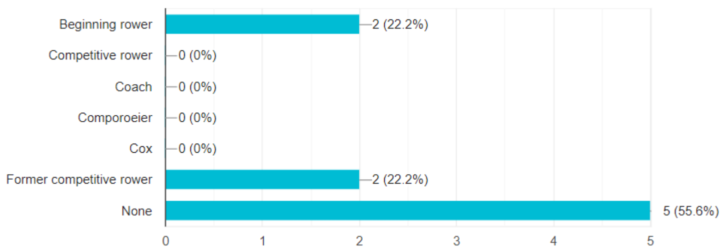

FIGURE 25: TYPES OF ROWERS PARTICIPATING IN THE USER TEST

distribution of these types of rowers is fine when it comes to beginning and non-rowers, but the intermediate level rowers are rather underrepresented. It would have been better for the user study to have approximately an equal level of beginner rowers and intermediate level rowers. As mentioned earlier, the focus thus does no longer lie on the difference between beginner and intermediate level rowers, but on the system with and without the power curve.

One of the questions in the survey was what feedback aspects the rower focused on the most. Multiple options could be selected. What is curious, is that none of the participants indicated that they used the watt plot, despite it being present in one of the two groups. This lack of indication can be blamed on the lagging nature of the system with the watt plot, but it is still curious that there was no focus on it at all.

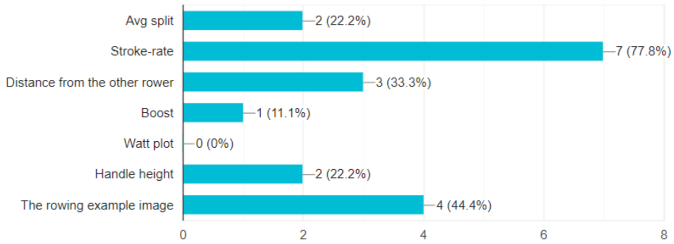

FIGURE 26: METRICS FOCUSED ON IN THE VR SYSTEM

To test on the reliability of the IMI questions, a reliability test was performed in SPSS. Cronbach's Alpha was used to test for internal consistency. If α=1, then all answers were the same for that subscale, and can indicate that the answers are reliable. However, when α starts to drop under 0.7, the reliability becomes questionable, turning to poor when it becomes lower than 0.6. The results from SPSS per subcategory of the IMI questions can be seen in table 3.

Subscale	**Cronbach's Alpha**
Interest / Enjoyment	0.829
Effort	0.684
Value / Usefulness	0.881

TABLE 3: CRONBACH'S ALPHA PER SUBSCALE OF THE IMI QUESTIONS

The subscales of the IMI questions did not differ significantly between the group with the power curve and the one without. However, a slight difference is noticeable in that the subscales of the group with the power curve scored higher than the one without. This can be seen in figure 27. In general, the participants enjoyed the experience, and were motivated to put effort in their rowing. The majority of the participants also expressed their interest in the system and that they would not mind doing this again.

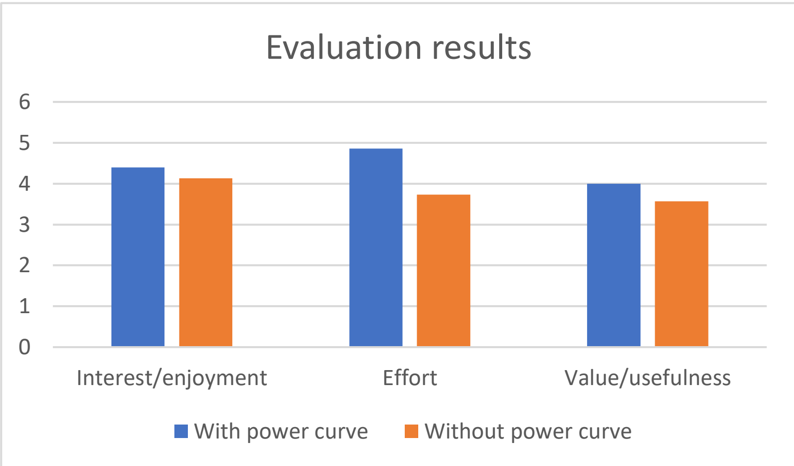

FIGURE 27: THE RESULTS FROM THE IMI EVALUATION QUESTIONS

6.2. **Limitations**

In this section, several limitations of the user test and the research as a whole will be given.

<u>Time period</u>

In order to be able to properly research the effects of adding the power curve to the system, the research might need a longer time frame to measure the long-term effects. Although five minutes might be enough for non-rowers to improve slightly, this phenomenon cannot be entirely attributed to the system, but instead can also be claimed to be from getting used to rowing in general. Furthermore, improvement in technique in intermediate level rowers can hardly be noticed after just five minutes of training with a new system. As one of the coaches mentioned, it is hard to get rid of movements that are ingrained, even if they stem from an incorrect technique. Changing these movements takes time, practice and conscious awareness of the movements, and are hard to change on a short term.

<u>User test</u>

Due to the time period, availability and the corona crisis, I have not been able to test a significant number of people. Especially when it came to rowers, it was hard to find people on a short term. This caused the user test unable to say something about the larger population. The difference in force curve might be the cause of different variables, and testing the system with a larger number of people might rule out more of these variables, and create a more valid test in general.

<u>Frame rate</u>

One noticeable issue during the user tests was the fact that the system which contains the power curve has to process a lot of data from the RP3. This may account for the fact that the framerate is either very slow during a rowing stroke, or the system freezes, disconnecting the HTC Vive temporarily from the VR environment. This prevented the participants from rowing properly, as the switch between the VR system and the HTC Vive home screen was too frequent at one point, confusing the participants. It can be noted, however, that some of the participants thought of it as a nice asset to the system, as they thought it to be part of it.

<u>Human error</u>

Due to the manner of recording the data, most of the data had to be processed by hand. This means that it had to be filtered from system declarations, and then the force data had to be put in Excel by hand. Furthermore, some of the graphs were missing data, or incorrectly declared, which made it difficult to find proper recordings. Manually moving the data also means that there is a chance that some of the data points are missing or incorrect, seeing as there are approximately 60 data points per curve. The data also needed to be extracted from the editor logs from unity, which is not the most reliable manner of storing data. During this process, the data of two of the participants inexplicably got lost, resulting in seven usable user tests instead of nine.

<u>Complexity of the system</u>

As mentioned earlier in the report, one of the research questions was centred around the implementation of the Oculus Quest 2. Despite Air Link making the transfer to this system a lot more feasible, the complexity of the Unity system makes adjustments to the system rather hard at times. Throughout the previous iterations, a lot of scripts, objects and references have been added, some of which are not in use. At times, it takes some searching to find the script or object you are looking for, and it might be in an unexpected place. When attempting to map out the location of all the objects and what scrips were attached to them, a rather large and intricate map was the result.

Not only is the Unity system complex, but also the components that allow the power curve to be available. These components need to be started in a specific order, and one issue in one system might lead to there being no data.

6.3. **Ethical risk sweep analysis**

In this chapter, the toolkit provided by the Markkula Center for Applied Ethics is used to solve different ethical problems and identify ethical risks of the project.

6.3.1. Ethical Risk Sweeping

As defined by the Markkula Center [34], ethical risks are "choices that may cause significant harm to persons or other entities with a moral status, or are likely to spark acute moral controversy for other reasons"[9]. It is essential that we identify and observe these risks, as they are the key to a good design, as well as engineering practice in general.

<u>Sports-related injuries</u>
Although it is often greatly discouraged, some people with (sports-related) injuries will to try out new ways to work out, or might like to try the system out of curiosity. If the person has injuries in the wrists, knees, legs, ankles, shoulders or back, rowing might further aggravate their injuries. Without being given a proper warning, people might overlook these chances, especially if the injuries are in areas not thought to be used in rowing (e.g. wrists or lower back).

<u>Motion sickness</u>
Some people might experience motion sickness because of the ergometer seat moving back and forth. This feeling can become worse by wearing a head-mounted device (HMD), which also has the capability of making a person feel motion sick due to the movement of the Virtual Reality world.

<u>Dissociative state</u>
Research [10] has proven that using an HMD in Virtual Reality causes the wearer to get into a dissociative state. This means that they feel disconnected from the real world, seeing as their sense of sight, and sometimes hearing, is entirely focussed on the VR world, leaving the person less aware of their direct environment as well as their own body up to a certain point.

<u>Screen time</u>
In the last few years, the amount of time people stare at screens has increased greatly. This ranges from mobile phones to computer screens to television to train station signs. New technologies are emerging all around us, and with the growing Internet of Things (IoT), we are seeing more screens in our daily life. This increased screen time, however, also increases the chance to develop short-sightedness or myopia. Furthermore, it decreases our time spent face-to-face, decreasing daily physical contact with other people.

<u>Privacy</u>
In order to give correct feedback to the rower, the system has to capture motion data. The downside of this is that this also allows someone with access to the system to figure out the rower's height, strength, and rowing strengths/weaknesses. Especially for professional rowers, this can pose a privacy risk.

<u>Wrong muscle memory</u>
While being able to learn the proper rowing posture sounds great, it might also be interpreted in the wrong way. This can cause a novice rower to gain the wrong muscle memory, which is hard to adjust later on. Furthermore, it might cause injuries instead of preventing them.

Accessibility of the system
Even though the system is intended for the general rowing audience, the system is still rather expensive, consisting of an HTC Vive, a desktop computer, and an RP3 Dynamic ergometer. For the average rower, this is often too expensive to afford. (see 3.1)

No backup
This system aims to take over part of the duties of the coach, seeing as they do not always have the time or capacity to manage all the rowers at one and give them proper feedback. However, the system cannot fully replace the coach, seeing as each individual is unique, and needs feedback especially for their situation, their capabilities and their goal. Furthermore, the rower might interpret the feedback wrong, in which case they need the corrective feedback from an experienced coach.

6.3.2. Ethical Pre-Mortem or Post-Mortems

Now that we have identified at least the majority of individual risks, we now have to look into pre-mortems and post-mortems: the systemic ethical failures. This is important, as the previously mentioned 'smaller' risks by themselves are minor, however, several smaller risks together might cause an ethical disaster. With pre-mortems, we mean the process of using the previously mentioned ethical risks to identify possible systemic ethical failures that might follow from them. Post-mortems, however, are the ethical disasters that have already occurred. Post-mortems are not as relevant for this project, however, seeing as it is still a prototype and has only been used in research and research-related user studies so far.

Novice rower at a rowing club
A novice rower has seen that VR Rowing is an option in the rowing club, and has decided to try the system out. Enthused by the VR environment, they start to use the system more often instead of going to the regular trainings. However, as a novice rower, they have accidentally misinterpreted some of the feedback given by the system, and have fallen in a wrong rowing technique. Due to this wrong muscle memory, over time, this causes them to get long-term injuries because of the VR rowing system. Not only is the rower now injured and has to recover for a long time, the rowing club as well as the manufacturer of the VR system might get in trouble if the rower makes a claim for compensation.

An enthusiastic, more experienced rower
An intermediate-level rower is getting bored with rowing on a regular ergometer, and wants to try something new. Interested by the new opportunity to row in a VR environment, they try out the system. At first, they are rowing in a slow, steady pace, observing their environment and enjoying the experience. Enthused, they begin to row faster and longer than they usually do on a regular ergometer, not feeling the strain on their body due to the induced dissociative state of the HMD. Suddenly, they begin to feel a sharp pain in their lower back, and stop rowing. The physiotherapist later tells them that they have a tear in one of their back muscles due to their excessive rowing.

6.3.3. Expanding the Ethical Circle

One overlooked issue is that researchers such as myself, when working mostly individually on a project without peer-to-peer reviewing of the system or constructive criticism by and involvement of the different stakeholders, some key stakeholder interests are easily overlooked. This is why we need to expand the ethical cycle and observe the effects of the project on (possible) stakeholders.

Beginning rowers at a rowing club
As mentioned earlier, novice rowers at a rowing club might be able to use the system in order to improve their rowing stroke, handle height, or to get more used to ergometer rowing in general. The interests of this group have been observed well, as several people under this category have been interviewed.

Intermediate-level rowers
The interests of beginning rowers have been observed, but we also need information from intermediate-level rowers in order to make the involved group larger. Especially in rowing clubs, there will also be a significant number of rowers who are no longer beginners, but are interested in using the project as well.

At home beginning rowers
There are people who are interested in rowing, but have no experience yet and have not yet joined a rowing club. The interests of these people have also been observed more closely, as this group has also been involved in the user testing of this project.

General public
Although this project is not meant to be placed in a normal gym, there is the possibility that this will happen somewhere in the future of this project. The interests of this group have not been observed too closely yet, due to them being an indirect stakeholder in the project, but further on in the project it might be interesting to observe whether their interests are different from the aforementioned groups.

6.3.4. Remembering the Ethical Benefits of Creative Work

It is important to not only look at the bad side of the project and everything that can go wrong. We also need to look at all the positive things that the project can bring.

More enjoyable ergometer rowing
Ergometer rowing is good for increasing strength, but can be boring from time to time. Especially for more advanced rowers, who often train 8 to 10 times per week. With the help of the VR environment, ergometer trainings can be made more fun, without losing the metrics of the ergometer. In this way, the rower can still increase their strength, but in a more enjoyable way.

Less injuries in beginning rowers
In rowing, long-term injuries are often caused by a wrong technique or posture. A normal ergometer does not give a lot of feedback on this, except a little through the power curve. This project assists the rower in identifying a wrong posture or technique, and correcting them. In the long run, this will prevent sports-related injuries in rowing, especially for novice rowers.

Get more people interested in the sport
When trying to get more people interested in rowing, one great way to do that is through such a VR environment. A person who is unfamiliar with rowing cannot immediately row on water without having to work on, for example, their balance first. This is why the VR environment can give them an impression of what rowing outdoors feels like, without having to work accurately on their technique yet.

Wider range of feedback
A normal ergometer often contains feedback in outcome (split time, burnt kcal, distance, etc.), and a bit on performance (power curve). The previous iterations of this VR system contained mainly feedback on performance (posture, handle height), and a bit of speed and distance to represent the feedback on outcome. With the addition of the power curve to the system, there is a wider coverage of the available feedback, which allows a rower to use the system without losing valuable feedback given by the ergometer.

Lessen the load on coaches
A coach often has 4 to 8 people to manage during each training indoors. Especially when these rowers are relatively new to rowing, this is a hard task. While it is true that it is easier to spot individual errors, the coach cannot give the rower their undivided attention. This project can help these coaches in lessening their workload per training, and while the project cannot replace the coach's tailored feedback and eye for individual errors, it can help push the rower in the right direction.

6.3.5. Think About the Terrible People

As much as we want to believe that only good use will be made of this project, we also have to keep in mind that this might not always be the case. This is why we have to look at the immoral ways in which the project can be used, when worst comes to worst. This allows us to come up with a plan to prevent this possible misuse of the system.

Hackers
The system, as previously mentioned, captures motion data from the rowers. If hackers were to get into the system, they could get the rowing data of the rowers using the system. This would pose a major privacy invasion, as this would be a big problem for professional rowers. Hence, a cyber security expert should be contacted to check the system and set up barriers to prevent hackers from getting the data.

Firing coaches
As mentioned earlier, this system is not meant to replace coaches in rowing clubs. However, there is a possibility that rowing clubs will fire some of their coaches, using this project as a replacement. To prevent this, the difference between feedback from the system and feedback from the coaches has to be highlighted, with the message that this system cannot replace a coach.

Thieves
Seeing as the system by itself is rather expensive, with some elements being easy to steal without supervision, it has to be secured against theft. Camera surveillance, wiring or screws can prevent the different parts from being stolen.

6.3.6. Closing the Loop: Ethical Feedback and Iteration

Despite having made an insight in some of the ethical risks of the project, this overview is not yet complete, and never will be. Especially as the project advances further in design and usage, reflecting on ethical implications has to continue as well. It is a loop, not a line. In order to prevent unrecognised ethical disasters from happening, we have to continue to reflect, so as to also ensure that we can make use of all the positive attributes of the project.

7. Conclusion

To conclude this report, a summary of the findings will be given. From these findings, conclusions will be drawn with regard to the main research question.

Virtual Reality is a broad field that has a lot of opportunities. These opportunities stem from the fact that in VR, we can do things that we normally cannot do in this world. Not only this, but a literature review showed that VR has a dissociative effect on the user, making it interesting to use in the field of sports. Individuals wearing the headset find themselves to pay less attention to their surroundings and the tiredness of their own body, allowing them to express more confidence in their sports and push to their limits.

In order to prevent long-term injuries in rowers using an ergometer, a VR rowing system was created to give feedback to the rower on their technique, posture and results. Through three iterations, starting with Koen Vogel[22], followed by Sascha Bergsma [4], and concluding with Annefie Tuinstra [21], this system was improved on different aspects, ranging from the environment, to competition, to multimodal haptic feedback. This research treads in their footsteps by reviewing the feedback present in the system and adding data from the ergometer to it.

Although the current system consists of a HTC Vive, three trackers, a PC and the RP3 Dynamic ergometer, there are also opportunities to switch the HTC Vive for the Oculus Quest 2. Not only is the Oculus untethered, it also does not require the lighthouses of the Vive, and can connect to the VR environment through the recently published Air Link. Furthermore, it's hand tracking abilities allow for a number of opportunities, which might compensate for the missing trackers.

Through consults with three rowing coaches and studying the literature, a clearer overview was made of the requirements such a system and the feedback in it should meet. Furthermore, it served as further confirmation that the current system supports the coach, and does not replace them, as the rower would still require knowledge of the basics of rowing.

The major addition to the system is currently the data from the ergometer. Using a Java Platform and an external server, the data from the ergometer is processed and sent to the Unity project, where data on the force, stroke length, generated power and energy, and the relative peak force position. This data was then used to generate a graph in the Unity scene, showing the rower their power curve.

A user test was then performed to test the effects of this addition by studying the force curves of the participants. The effects were, however, shown to be minimal. The errors in the system with the graph and the small number of participants certainly might have had an effect hereon, and the majority of the participants did not use the curve to improve on their technique. The non-rowers were focused mainly on the different types of feedback on their technique, while the rowers focused more on their results, this being the stroke rate, speed, and distance from the opponent.

As explained in this report**,** there is no 'perfect' power curve. That having said, there is still a number of visual aspects that we can take into account. From these visual aspects, we can conclude that the majority of the force curves have become smoother after having used the system. They all showed to be non-normal, which was to be expected, however, the kurtosis and skewness might be usable to set a standard for what level of skewness and kurtosis are still acceptable for a power curve.

The survey that followed supported the research in used metrics within the scene, and showed that despite the shortcomings of the system with the power curve, the participants were still enjoying the experience, and improving on their power curve.

8. Recommendations

8.1. **Improvements**

There are several points that this current system can be improved on. First, the complexity of the system is something that makes it hard to adjust parts, and when an error occurs, this can come from many different places. Especially seeing as some objects or scripts are not in use or hidden. Some objects are placed in odd places in the hierarchy, which at times makes it hard to find a specific object or which scripts are connected to which objects. The haptic feedback from the second iteration, for example, has interesting opportunities, but this system is currently not in use. It would be valuable to look at the different aspects and attributes of the current system, both those in use and those that aren't, and this might lead to an entirely new VR experience.

Another obvious point of improvement lies with the power curve. As of now, the system has a tendency to freeze during longer use of the system. The cause of this might lie in the large quantities of data it has to process, or perhaps one of the queues blocks while waiting for data, which might be blocking the remainder of that script.

Related to this is the speed of the skiff. The system was initially changed so that the skiff speed was no longer dependent on the speed of the handle, but instead of the incoming force data. However, due to the aforementioned problem, as well as some others, this proved to be hard. First, while Java uses decimal points, Java uses commas. This causes the data sent to Unity to be terribly large. This makes the data rather inaccurate as well, seeing as a data point with more decimal numbers is larger in Unity.
Related hereto are the Java scripts. As someone who is not as well versed in Java programming, I have gotten some parts to work in a rather 'expensive' manner, such as infinite while loops. The current scripts work, but they might require someone with more knowledge on the topic to improve them.

8.2. **Expanding**

When it comes to the user tests, there would still be some benefits to performing this test on a broader scale, where a proper distinction can be made between the results of the rowers and the non-rowers. This test might also benefit from being done over a longer period, as change cannot often be significantly noticeable within a short timeframe as this research.

During the previous iterations, some other opportunities for improvement were mentioned. First, converting the system to a high definition render pipeline might make the experience more immersive [21]. However, the aforementioned complexity of the system makes this switch quite a challenge.

There lie also lots of opportunities in the present power curve. Instead of merely showing it to the rower, the system could also be used to highlight the parts of the power curve that the rower can improve on, and what bumps mean, for example, and how to prevent these.

Lastly, the coaches noticed that the split time is in meter per second, instead of time per 500m, so some adjustments might be made here.

8.3. **Future Work**

As the reader might have noticed, this project has many opportunities as well. First, the implementation of the Oculus Quest 2 would be an interesting development. Over the course of this research, implementing the Quest appeared to be feasible, especially with the Air Link that has been published. The implementation of the Quest would not only make the system more affordable, but would also allow for more ergometers to be in the same room, as the Quest does not need the lighthouses. The Quest also is not tethered, in contrast to the HTC Vive. This issue can also be solved with the Wireless addition to the HTC Vive, which allows it to run wireless for a certain amount of time, so the differences between these systems would be interesting to research. The matter of the lack of trackers also has a range of solutions: for example, the two controllers of the Quest can be used to replace two of the HTC Vive trackers. To compensate for the last tracker, one might consider using a calibration system to calculate the average position of the last tracker. Furthermore, the Quest contains hand-tracking, which might also prove to be meaningful for this system. Especially considering the time and effort it takes to charge, calibrate and bind the different HTC Vive trackers.

The data from the RP3 also makes way for many opportunities. This data is nearly real-time available in Unity, and does not only need to be used for the force curve. The availability of the force and drive data allows for exciting opportunities, especially in VR. This data can be used to make the environment more accurate, or to give different types of feedback to the user in interesting ways.

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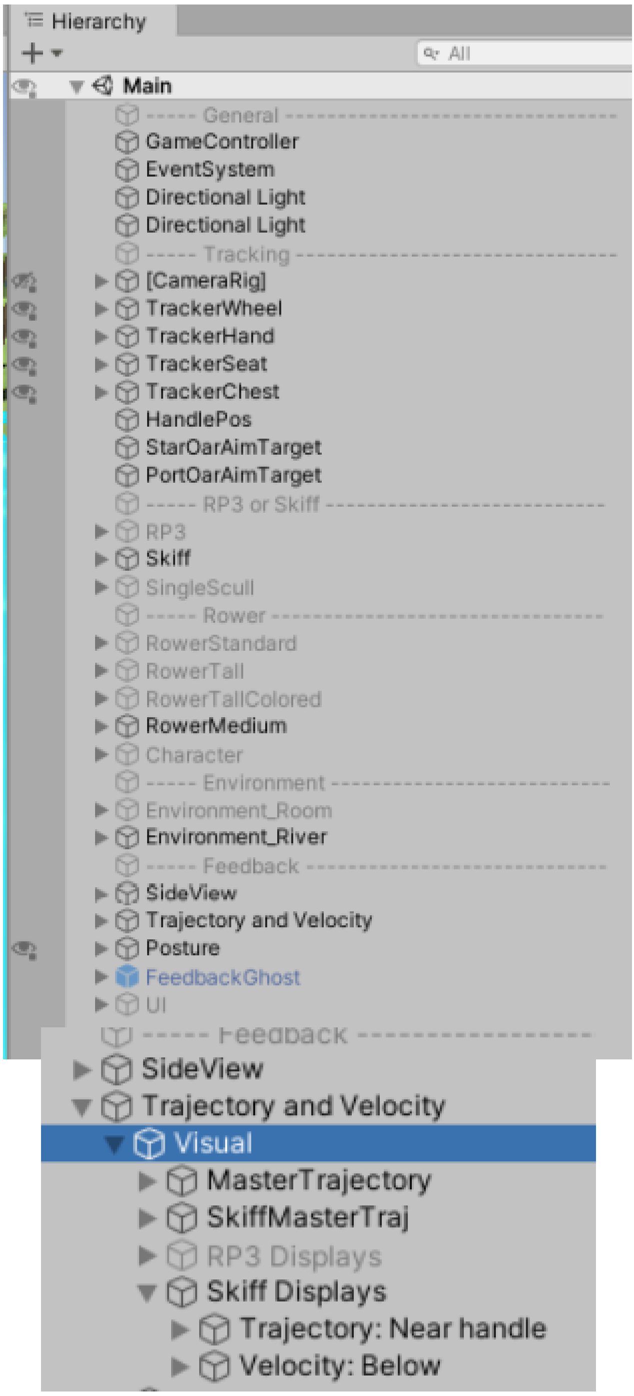
WORCESTER POLYTECHNIC INSTITUTE In partial fulfillment for the Degree of Bachelor of Science.

Appendix A: Manual

The existing virtual rowing coach is a VR system that consists of a VR headset, 3 motion tracking devices and an ergometer. The system is able to let the user know whether their handle height, back movement and sliding speed is accurate when doing normal rowing strokes. The system is made in Unity and launched through SteamVR. In this manual, the boot setup will be explained and a quick overview of the different functions will be explained.

A.1. Quick overview

For a showcase of the current system, this video is available to watch: https://www.youtube.com/watch?v=kD93bxN2cQ4&ab_channel=SaschaBergsma



This is the main setup when opening the project. [img]

In the hierarchy, different game components can be found.
General:
General Unity game components.
Tracking:
These are the different motion sensors on the wheel, hand, seat and 'chest' (the headset). It also contains a handle positions and oar targets, this has to do with the oar motions so that they rotate around a realistic point on the rigger (for animation purposes)
RP3 or skiff:
Here there is a choice to display a rowing machine, Empacher skiff or a regular boat-shaped object.
Rower:
Here different sizes of rowers can be chosen. This is important for calibrating the VR system as otherwise the feedback will not be accurate and the animation will look odd in the case a tall person has a very small avatar.
Environment:
Choose between a river-like environment or a simple room in VR.
Feedback:
These are the different feedback systems designed to correct the most common technique errors with novice rowers. SideView is the animation that displays when the back posture is not accurate. It displays the player from the side. This animation is visible in front of the user the moment the movement is wrong. Trajectory and velocity is about the handle height and speed. This feedback system consists of three parts: Visual, Auditory and Haptic. This will be dissected a bit more below.

- Visual
    - In the visual tab, there are four subtabs. These are about the Skiff Trajectory, which differs a bit from the RP3

trajectory: The skiff trajectory takes the width of the distance between hands into account (just like in a real boat). MasterTrajectory is about the drawing of the trajectory. The location is a 1000 blocks away, this is because all other trajectories essentially compare their movement with this one. It is so far away so it is not possible to see and so it does not interfere. SkiffMasterTraj is the trajectory that can be seen when rowing in a skiff.

    - RP3 displays is what can be seen when enabling the RP3. (the blue one) It is possible to choose here between a side display of the trajectory (to the right in VR vision) or an immersive display (directly underneath the user)
    - SkiffDisplays is the yellow one. It has a curvature, this is different from the RP3 trajectory.
- Auditory (U)
    - A remnant of Sascha Bergsma's project. In the auditory tab, the left hand sound, deviation sound and immersive sound can be seen. In the left ear, a sound with a certain pitch is played. On the right, a sound is played with corresponds with the handle height (i.e. when moving the handle upwards, the pitch gets higher). The idea with this feedback system is to match the left pitch with the right one by adjusting the handle height.
- Haptic (U)
    - A remnant of Sascha Bergsma's project. Using the glove with built-in motor, haptic (vibrations) feedback can be given. These vibrations indicate whether the handle movement is too fast or too slow. In the case the user

Posture:
This feedback system calculates the back angle and shows the user a sideview of himself in the case he does this incorrectly.
Feedback ghost: (U)
This is the remain of Koen Vogel's rowing project.
UI: (U)
The old UI that Koen Vogel used.

A.2. Booting the system

The setup uses SteamVR and Unity. First, make sure to install Steam and SteamVR (this is found in the Steam store for free). Note: This takes up 6 GB of storage space.
Open Steam and start SteamVR. When it has started, two or three small windows will pop up on the right. This is the VR hub that you can access all the time. Now, also open the Unity project.

Room equipment
To setup your room for VR, visit the Vive website for tips about the lighthouses and equipment.
https://www.vive.com/eu/support/vive/category_howto/installing-the-base-stations.html
Make sure that the base stations work. In the VR hub you can see the icons of the equipment you have. If one of the base stations is greyed out, this means that they cannot find eachother. Make sure that when using the sync cable (3.5mm cable), one base station is set to 'A' and the other to 'B'. If you do not use the sync cable, make sure one is set to 'B' and the other to 'C'.
If the icons are blue and not blinking, the base stations are ready.

Calibration

The calibration and order of all trackers and the headset is very important in order for the system to work optimal. This is why a step-by-step approach will be used for this part.

1. Open the ‘room setup’ by either selecting it in the steam library or selecting it from the menu of the VR hub by clicking
2. Make sure to choose the ‘standing only’ room setup.
3. The next step is checking if all ‘controllers’ and the headset are ready. In this step, turn on the trackers in this order:
   a. Flywheel
   b. Hand
   c. Seat

To turn on the trackers, press to turn them on, and then press and hold. This will make the tracker connect.

Make sure that the trackers are connected to the computer. To check this, look at whether the LED on the tracker is green. If this is not the case, they have to be reconnected. Click and select the option to connect a new tracker/device. Make sure to click ‘I want to connect a different type of controller’.
More information:
https://www.vive.com/us/support/wireless-tracker/category_howto/pairing-vive-tracker.html 5.

4. In the step to calibrate the ‘center’, make sure the headset is on the seat of the RP3, directly facing the flywheel. Make sure that the seat is behind the white tape found on the side of the sliding. Click calibrate.
5. When calibrating the floor, also make sure the headset is facing the flywheel, but then on the ground. Click calibrate.
6. Now to start the software in VR, click play in Unity. This will boot the software on the headset.

Troubleshooting

A few errors or mistakes can come up when booting the system. The most common issues: -

- The handle, user or seat is attached to the base station. This can be recognized by one of these components facing upwards or moved to a weird position. This is due to incorrect order of booting the trackers. Turn off SteamVR and Playmode in Unity and try again.
- The user is facing the wrong way. Make sure the headset is directly looking at the flywheel and levelled correctly on the seat when calibrating.
- One of the trackers is a handheld controller instead of a tracker; this can be recognized by a blue laser and an annoying pop up screen in VR. To fix this, turn of one of the other trackers and turn on a Vive controller. Select a different binding: Vive tracker. Then close, turn off the controller and turn on the tracker again. If it persists, turn off SteamVR completely and re-do the setup (this can do the trick)

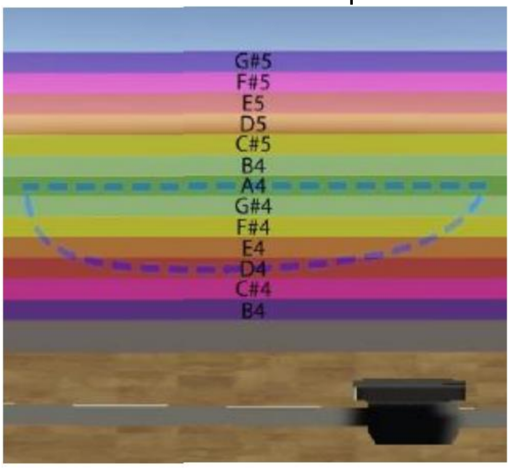
A.3. Using the feedback system

The three most common technique errors for beginning rowers are used in this project. Here there will be a more practical description about each of them.

Target trajectory
The handle height is one of the factors for feedback. The user is supposed to follow the pattern of the blue trajectory with their handle. The path the user takes can be seen as well because of the red line that is being drawn by the handle. If the user replicates the shape of the trajectory somewhat well, the trajectory will disappear. It only reappears when the user deviates from the shape too much. Often, beginning rowers move their handle excessively in vertical movements so this feedback system may correct this.

To turn it off/on:
Go to 'Trajectory and Velocity' tab in the hierarchy. Make sure the options are set like this: (see image to the right).
Optionally, it is possible to switch between trajectory and velocity, or select them both. The options in RP3 display dropdown can also be altered.
Also make sure that in the tab 'posture' in the hierarchy, the visual posture is set to active if a side view in front of the user is desired.

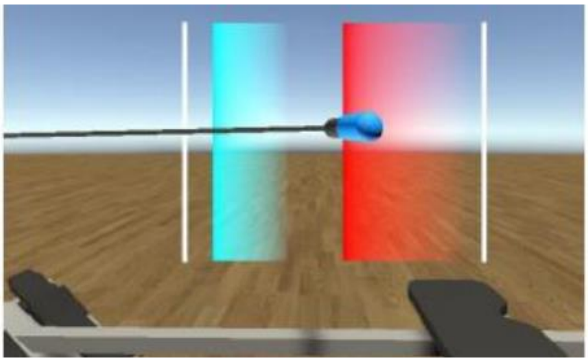
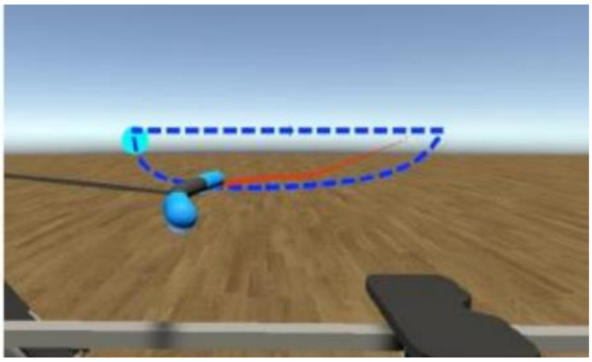
Auditory feedback
Although currently unused, Sascha has made auditory feedback depending on the target trajectory. In the left ear, a sound with a pitch can be heard. This pitch is the 'correct' handle height. In the right ear, the handle height of the user can be heard. The different pitches with heights can be seen in the picture to the right here. So, if a user moves their handle vertically upward, the pitch will become sharper and if moved downwards, the pitch will be flatter. The goal for the user is to match the pitch left with right. Left will differ between an A and a D as seen in the image to the right. Again, if the user performs this task correctly, the sound will disappear and only reappear when he/she does this wrong.



To turn it off/on:
Click on Auditory in hierarchy, and select 'On' in the sound dropdown list (inspector). It is possible to choose between skiff and RP3.

Velocity feedback
This feedback is also currently unused. Not only the height of the handle, but the speed is also important. Generally, when doing 'standard' strokes, the speed of the recovery will be about 1.5-2 times longer than the stroke. Feedback about the speed of the handle from the user is animated as seen below on the left image. This feedback combined with the trajectory feedback can also result in a blue ball moving around the trajectory. The speed is not set; every time the user starts a new stroke, the new stroke speed is calculated. This is more practical for users because if the user wants to drive the tempo up, the feedback will still work. Velocity is thus both visual and haptic. When the user is not following the speed

correctly, The vibrating motor in the glove turns on. When the user is following the ball correctly again with their handle, the vibration disappears.

To turn on velocity feedback:
Click ‘visual’ in the hierarchy. Check the ‘velocity’ box. Alternatively, the feedback can also be displayed in an immersive manner in the dropdown list of RP3 display, this will make only the velocity feedback directly under the user’s nose.

To turn on vibrations:
Click ‘haptic’ in the hierarchy. Select ‘on’ in the vibration dropdown. Choose between RP3 and skiff. In the glove, turn on the power bank (make sure it is charged).

Posture

This feedback is combined with ‘Sideview’: it lets the user know whether their back posture is correct. This can also be seen in the image on the right.
Unity is constantly tracking the back rotation of the rower in use and the example rower. As seen in the script ‘CalculateDeviation’, the difference in angle from the example rower and the user is being compared. If the difference is too big, the example rower will be displayed in the view until the user is somewhat similar again. the way this image is created is with another example rower in the scene. This rower cannot be seen as it is hidden in the environment, but it is constantly ‘rowing’ on the correct tempo. By disabling the river environment, this example rower can be seen. The rower is made red to show the user the difference.

To turn on posture feedback:
Go to ‘visual’ in the hierarchy, and make sure that the RP3 display dropdown is set to ‘side view’. Then go to ‘posture’ in the hierarchy, and check the ‘active’ box. It is possible to choose from different feedback views. ‘Whole’ means that the rower including the oars will be displayed, ‘only body’ means only the body (obviously) and capsule is only a capsule that imitates the back movement of the rower.

Other practical things

- How does the terrain keep on generating? This is due to a script called ‘SetRenderQueue’. This makes sure that the terrain is respawned about 3000 times, which is enough space for one training session.
- To check/test small things without having to put the headset on, it is also possible to select the ‘TrackerHand’ object in the hierarchy and move it along (in play mode).

A.4. Using the RP3 data

To boot the system to generate a power curve, several components are to be taken into account. First, the wire belonging to the RP3 has to be connected to the computer, preferably COM3, as the Java Platform is reading COM3 currently.

Next, the Label305 server needs to be started up. The server can be found in a related Label Data folder. Here, open Windows PowerShell, and enter 'java -jar rp3socketserver.jar'. This will start the server. This system can be tested by opening another PowerShell, and entering 'java -jar rp3socketclient.jar' causes the server to read a .txt file from the folder, which contains pre-recorded data. However, after this test, the server needs to be restarted.

Next, the Java Platform needs to be run. This can be done currently through Eclipse IDE for Java Developers. The main script, OpenSerialConnection, has to be started. This script starts the different threads by itself. After a short moment, the program should connect to the RP3. This can be tested by doing some strokes on the RP3. An important note is that when the Java system is stopped, the PowerShell server also needs to be restarted.

Lastly, the Unity system can be started. Starting or stopping the Unity system has no effect on the other two programs, as they can be run independently from Unity. Contrary to the Java Platform, Unity will not receive any data if there is no force or drive data available.

Appendix B: Consent Form

Ptcpt no.

TOESTEMMINGSVERKLARING (INFORMED CONSENT)

Concerning
The University of Twente and Human Media Interaction are researching the use of virtual reality and motion tracking to provide engagement and feedback on rowing technique, as explained in the brochure "Feedback in Virtual Reality Rowing" as given together with this form.

Main researchers:
Ilse Westra[1], Robby van Delden[1,] Daniel Davison[1], [1]University of Twente

Contact information
For questions you can contact Ilse Westra [redacted] or the Ethics Committee of the University of Twente [redacted]. The Ethics Committee exists of independent experts from the university and are available for questions and complaints surrounding this research.

Research Feedback in Virtual Reality Rowing
I hereby declare the following for the test in the 2020/21 rowing season:

- I give consent for my participation during the experiment and for the collection and use of data as described in the information brochure.
- I declare that I am fully informed about the research. The purpose, methods and possible risks are explained, and I had the possibility of asking questions.
- I understand that I can quit my participation at any moment during or after the test without a reason and without any consequences. In this case I can have the gathered data deleted if I wish.

Recordings will solely be viewed by UT researchers and will never be made public or used in demonstrations, presentations, promotions or media. All data will be stored anonymously for 10 years on a GDPR-secure server, according to the GDPR guidelines. The anonymous data, including movement data/survey responses might be made part of a publicly available corpus.

☐ I give consent for making video recordings for research purposes.

☐ I give consent for the publication of anonymous data collected during my participation in the research in the ways mentioned in the brochure.

Date: Place:

Name: Signature participant:

………

Appendix C: Information Brochure

Virtual reality is a new, disruptive technology that can be used for a variety of things. At the University of Twente, it is used for game implementations and sports technology. This research has the goal to create an environment for beginning rowers that can help them learn how to row correctly.

The installation consists of several motion trackers, connected to a virtual reality system. When rowing with the goggles on, it is possible to train in a realistic rowing setting and improve technique by receiving feedback. This feedback can, for example, be the height of the handle during a rowing stroke, or the angle of the back. Giving accurate and relevant feedback while rowing as well as afterwards, will help new rowers to improve their rowing.

This research, led by the University of Twente, is now in development by Ilse Westra. To develop this research further it needs testing with the desired target group. This way we can design a new future of rowing together with you! Will you help us by participating?

HMI GROUP
UNIVERSITY OF TWENTE.

UNIVERSITY OF TWENTE.

INFORMATION BROCHURE

Project: Feedback in Virtual Reality Rowing

This brochure provides information about the 'Feedback in Virtual Reality Rowing' project to help you decide to participate in the research.

[redacted]

Participation

You can voluntarily participate when aged 18 or older. At any moment you can indicate you want to quit the research without a reason or consequences. Consent for participation only has to be given once and is then valid for the rest of the experiment.

What happens exactly during the activities?

A single activity will last approximately 30 minutes. You will be asked to use a rowing machine while wearing a virtual reality headset and a glove with a motion tracking device. The activities are meant for you to understand the basics of rowing and to improve by receiving feedback. Mainly, the effect of the different feedback aspects will be researched. After this, you will be interviewed about the experience.

Are there any risks?

Please note that there is a known risk of motion sickness when immersed in virtual reality. Not many moving elements will be shown so the risk should be small. In case of physical discomfort, please stop the test by removing the headset. Furthermore, if you have injuries related to rowing or in your back, legs, knees or shoulders which might be aggravated by rowing, please do not participate. If you start to feel pain or discomfort, please stop your rowing movements. In the case of stopping, your data can be deleted within 24 hours of the test, if wished.

What data will be collected?

After the test, you will be asked to fill in a survey about the test in order to gather personal information like age and gender. Possibly some additional questions will be asked about the experience. During the activity video recordings will be made from the side, which will include the face, and motion sensor data will be used during the experiment.

How is the data used?

The data will be analyzed primarily for a bachelor thesis, in an observational analysis. The data can be published after on the open-access website essay.utwente.nl and in regular media, where it will be anonymized. This data can also be used for future research on this topic.

The above does not count for the video recordings, which will only be accessible by the people involved in the research. The names of these people can be acquired on request by contacting Ilse Westra. The video recordings will not be published on either internet media or presentations/demonstrations.

A part of the anonymous data can be made public for future research by others, which is why consent for this is separately asked on the consent form.

How is the data stored?

The data of video recordings, motion sensors and survey results will be safely and anonymously stored according to the guidelines of GDPR/AGV. The data can be stored for up to 10 years, according to the VSNU guideline.

Can I ask to delete data?

If you wish to stop the experiment, then this is possible during, before or after the experiment. If this is the case, then within 24 hours of the testing, your data can be deleted. Video recordings will be showed afterwards to you, so you are aware of what is recorded.

All data that is anonymized is no longer connected to you, so this can not be deleted any longer.

More information and advice

For questions directly related to the project, please contact Ilse Westra (contact info is found at the front side of this brochure)

Would you like independent advice about the research or file a complaint? This is possible by contacting the Ethics Committee [redacted] The committee is independent from the university and is available for questions related to this research.

Appendix D: Survey Questions

This questionnaire follows the experiment done for my graduation project, Feedback in Virtual Reality Rowing. The goal of this research is to improve the feedback given in an already existing VR environment. This environment exists to help novice and intermediate rowers to improve on their rowing technique and performance without the supervision of a coach. The survey will take about 10 minutes.

If you want more information on the topic, you can ask me in person or contact me, Ilse Westra.

This form will be used to be able to analyse the motion data of the experiment further. This form will be anonymous, and the data will be stored on a GDPR-safe server indefinitely, according to the guidelines of the server. If you wish, some or all of the data can be removed by request. Do you agree on sharing your data to be used in this graduation project, as well as potential future research on this topic?

- Yes / No

D.1. Background and System Questions

The following questions are asked for further analysis of the motion data.

- What is your age? (18-24; 25-30; 30+)
- What is your height?
- I am a (competitive rower; beginning rower; coach; 'comporoeier'; cox; former competitive rower; none of the above;)
- How many years of rowing experience do you have, if applicable?
- How many years of coaching experience do you have, if applicable?
- What type of rowing machine do you have experience with?
  - RP3
  - Concept 2
  - None

The following questions are all on a scale of: Agree Fully – Agree – Average – Disagree – Disagree Fully

- I get enough feedback on results from the ergometer
- The data on my screen says a lot about my results
- I use the data to improve my results during ergometer rowing
- During rowing, I pay attention to the data on my results
- I look at my data to assess how well I am doing
- Without a coach, I still know how to improve my results using the ergometer based on the data on my screen

- I get enough feedback on my technique from the ergometer.
- The data on my screen says a lot about my technique
- I use the data to improve my technique during ergometer rowing
- During rowing, I pay attention to the data about my technique
- I look at my technique to assess how well I am doing

- Without a coach, I can still learn how to row correctly using the ergometer based on the data on my screen
- The data I use in my rowing practice are … (500m split / avg split/ stroke-rate / total time / total dist / watt plot / other)
- What kind of data would you like to see on your screen other than the data that is already presented?

E.1. IMI Evaluation Questions

1. I enjoyed doing this activity very much
2. I didn't try very hard to do well at this activity
3. I would be willing to do this again because it has some value to me
4. I think doing this activity could help me to improve on my performance in rowing.
5. I didn't put much energy into this.
6. I think that doing this activity is useful for increasing my performance in rowing.
7. This activity was fun to do.
8. I believe doing this activity could be beneficial to me
9. This activity did not hold my attention at all.
10. While I was doing this activity, I was thinking about how much I enjoyed it.
11. I put a lot of effort into this
12. I think doing this activity could help me to improve on my technique in rowing.
13. I think this is important to do because it can help me to improve my technique
14. I tried very hard on this activity
15. I thought this was a boring activity.
16. It was important to me to do well at this task.
17. I believe this activity could be of some value to me

Interest / Enjoyment: 1, 7, 9(R), 10, 15(R)

Effort: 2(R), 5(R), 11, 14, 16

Value / Usefulness: 3, 4, 6, 8, 12, 13, 17

Appendix E: Scripts

E.1. RP3 Data Unity

```
using System;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Net;
using System.Net.Sockets;
using System.Security.Cryptography.X509Certificates;
using UnityEditor;

public class RP3_Data_Receiver : MonoBehaviour
{

        public static List<float> RP3DataPoints = new List<float>();
        // force
        public static float ForceReceivedTimestamp;
        public static float m_strokeLength;
        public static float forceNewton;

        // drive
        public static float power_watts;
        public static float relative_peak_force_position_fraction;
        public static float energy_joules;

        private String forceReception;
        private String driveReception;

        private static float ForceTimeout = 0.4f;

        Socket socket;
        Socket driveSocket;
        byte[] buffer = new byte[1024];
        byte[] driveBuffer = new byte[1024];

        void Start()
        {

                socket = new Socket(AddressFamily.InterNetwork, SocketType.Dgram,
                ProtocolType.Udp);
                socket.Bind(new IPEndPoint(IPAddress.Any, 8888));
                socket.Blocking = false;
                driveSocket = new Socket(AddressFamily.InterNetwork, SocketType.Dgram,
                ProtocolType.Udp);
                driveSocket.Bind(new IPEndPoint(IPAddress.Any, 8887));
                driveSocket.Blocking = false;
                StartCoroutine(Poll());

        }
        IEnumerator Poll()
        {
```

```
while (true)
{
    yield return new WaitForSeconds(0.01f);
    if (socket.Poll(0, SelectMode.SelectRead))
    {
        int bytesReceived = socket.Receive(buffer, 0, buffer.Length,
        SocketFlags.None);
        if (bytesReceived > 0)
        {
            forceReception = Encoding.ASCII.GetString(buffer, 0,
            bytesReceived);
            Debug.Log("got force data: " + forceReception);
            if (forceReception != null)
            {
                Char[] separators = new Char[] {',', ':', '{', '}'};
                String[] subs = forceReception.Split(separators,
                StringSplitOptions.RemoveEmptyEntries);
                m_strokeLength = float.Parse(subs[1]);
                forceNewton = float.Parse(subs[3]);
                ForceReceivedTimestamp = Time.time;
                Debug.Log("We got force data at time: " +
                ForceReceivedTimestamp);
            }
            else
            {
                m_strokeLength = 0;
                forceNewton = 0;
            }
            RP3DataPoints.Add(forceNewton * 6e-15f);
        }
    }
    if (driveSocket.Poll(0, SelectMode.SelectRead))
    {
        int driveBytesReceived = driveSocket.Receive(driveBuffer, 0,
        driveBuffer.Length, SocketFlags.None);
        if (driveBytesReceived > 0)
        {
            driveReception = Encoding.ASCII.GetString(driveBuffer, 0,
            driveBytesReceived);
            Debug.Log("got drive data: " + driveReception);
            if (driveReception != null)
            {
                Char[] separators = new Char[] {',', ':', '{', '}'};
                String[] subs = driveReception.Split(separators,
                StringSplitOptions.RemoveEmptyEntries);
                power_watts = float.Parse(subs[1]);
                relative_peak_force_position_fraction =
```

```
                                        float.Parse(subs[3]);
                                        energy_joules = float.Parse(subs[5]);          }
                                        }
                              }
                         }
                    }
               }
```

E.2. Java Open Serial Connection

```
package SerialConnector;
import SerialConnector.OpenSerialConnection;
import java.io.IOException;
import java.io.InputStreamReader;
import java.io.PrintWriter;
import java.net.Socket;
import java.util.concurrent.LinkedBlockingQueue;
import java.io.BufferedReader;
import java.io.DataInputStream;
import gnu.io.NRSerialPort;

public class OpenSerialConnection extends Thread {

     private static final String COM_PORT = "COM5";
     private static final String serverIP = "localhost";
     private static final int mainPort = 3333; // this also receives the force data
     private static final int drivePort = 3334;

     private Socket mainClientSocket;
     private Socket driveClientSocket;

     private PrintWriter dataToServer;
     private ForceListener forceListenerThread;
     private DriveListener driveListenerThread;
     private ForceSender forceSenderThread;
     private DriveSender driveSenderThread;

     private BufferedReader forceIn;
     private BufferedReader driveIn;

     private DataInputStream dataInput;
     private LinkedBlockingQueue<Float> pulseData;

     public OpenSerialConnection() {

          pulseData = new LinkedBlockingQueue<Float>();

     }
     public void init() {

          initRP3Connection();
          initSocketConnections();

     }
     public void initSocketConnections() {
```

```
try {

        mainClientSocket = new Socket(serverIP, mainPort);
        dataToServer = new PrintWriter(mainClientSocket.getOutputStream(), true);
        forceSenderThread = new ForceSender();
        forceSenderThread.start();
        driveSenderThread = new DriveSender();
        driveSenderThread.start();

        forceIn = new BufferedReader(new
        InputStreamReader(mainClientSocket.getInputStream()));
        System.out.println("FORCE: Connected to server on IP "+ serverIP +" and
        port "+ mainPort);
        forceListenerThread = new ForceListener(forceIn, forceSenderThread);
        forceListenerThread.start();

        driveClientSocket = new Socket(serverIP, drivePort);
        driveIn = new BufferedReader(new
        InputStreamReader(driveClientSocket.getInputStream()));
        System.out.println("DRIVE: Connected to server on IP "+ serverIP +" and port
        "+ drivePort);
        driveListenerThread = new DriveListener(driveIn, driveSenderThread);
        driveListenerThread.start();

    } catch (IOException e) {

        // TODO Auto-generated catch block
        e.printStackTrace();

    }

}
public void initRP3Connection ()
{

    int baudRate = 9600;
    System.out.println("Connecting on to the RP3 on port: " + COM_PORT);
    NRSerialPort serial = new NRSerialPort(COM_PORT, baudRate);
    serial.connect();
    dataInput = new DataInputStream(serial.getInputStream());

    //the value we get from RP3 is split in 2 consecutive bytes, we read the first byte, shift
    it left and then add the second byte
    //the resulting integer (between 0..65535 or so) is then converted to a float by dividing
    by 750000 (for some reason)


}
@Override
public void run() {

    try {

        while(!Thread.interrupted()) {// read all bytes
        if(dataInput.available()>=2) {

            int firstByte = (int) dataInput.read() & 0xff;
            firstByte = firstByte << 8;
            int secondByte = (int) dataInput.read() & 0xff;
            int totalValue = (firstByte | secondByte) & 0xffff;
```

```
                    float value = (totalValue / 750000.0f);
                    System.out.println("Got new data, adding to queue: "+
                    String.valueOf(value));
                    pulseData.put(value);

                }

            }

        } catch (IOException e) {

            e.printStackTrace();

        } catch (InterruptedException e) {

            // TODO Auto-generated catch block
            e.printStackTrace();

            }

        }

        private void sendData() {

            while(true) {//add some kind of stop-clause

                try {

                    float newValue = pulseData.take();
                    String strVal = String.valueOf(newValue);
                    System.out.println("Sending to server: "+strVal);
                    dataToServer.println(strVal);
                    dataToServer.flush();

                } catch (InterruptedException e) {

                    // TODO Auto-generated catch block
                    e.printStackTrace();

                }

            }

        }

            public static void main(String[] args) throws IOException
        {

            OpenSerialConnection connWithRp3 = new OpenSerialConnection();
            connWithRp3.init();
            connWithRp3.start();
            connWithRp3.sendData();

        }

}
```

E.3. Java Drive Listener

```
package SerialConnector;
import java.io.BufferedReader;
import java.io.IOException;
```

```
public class DriveListener extends Thread {

    private BufferedReader incomingDriveMessages;
    private DriveSender driveSender;
    public DriveListener(BufferedReader incomingDriveMessages, DriveSender driveSender) {

        this.incomingDriveMessages = incomingDriveMessages;
        this.driveSender = driveSender;

    }

    public void init() throws IOException {

    }
    @Override
    public void run() {

        String line = "";
        try {

            while((line = incomingDriveMessages.readLine()) != null) {

                System.out.println("Got drive from server: "+line);
                System.out.println("Got new drive data, adding to queue: "+
                line);
                driveSender.getDriveDataQueue().put(line);

            }

        } catch (IOException e) {

            // TODO Auto-generated catch block
            e.printStackTrace();

        } catch (InterruptedException e) {

            // TODO Auto-generated catch block
            e.printStackTrace();

        }

    }

}
```

E.4. Java Force Listener

```
package SerialConnector;
import java.io.BufferedReader;
import java.io.IOException;

public class ForceListener extends Thread {

    private BufferedReader incomingForceMessages;
    private ForceSender forceSender;

    public ForceListener(BufferedReader incomingForceMessages, ForceSender forceSender) {

        this.incomingForceMessages = incomingForceMessages;
        this.forceSender = forceSender;

    }
```

```
	public void init() throws IOException {

	}
	@Override
	public void run() {

		String line = "";
		try {

			while((line = incomingForceMessages.readLine()) != null) {

				System.out.println("Got force from server: "+line);
			System.out.println("Got new force data, adding to queue: "+
			String.valueOf(incomingForceMessages));
			forceSender.getForceDataQueue().put(line);

		}

	} catch (IOException e) {

		// TODO Auto-generated catch block
		e.printStackTrace();

	} catch (InterruptedException e) {

		// TODO Auto-generated catch block
		e.printStackTrace();

	}

}

}
```

E.4. Java Drive Sender

```
package SerialConnector;
import java.io.IOException;
import java.net.DatagramPacket;
import java.net.DatagramSocket;
import java.net.InetAddress;
import java.util.Scanner;
import java.util.concurrent.LinkedBlockingQueue;

public class DriveSender extends Thread {

	private LinkedBlockingQueue<String> driveDataSendQueue;
	public DriveSender() {

		this.driveDataSendQueue = new LinkedBlockingQueue<String>();

	}
	public void init() {

	}
	public LinkedBlockingQueue<String> getDriveDataQueue(){

		return driveDataSendQueue;
```

```
	}
	@Override
	public void run() {

		sendDriveData();

	}
	private void sendDriveData() {

		// TODO Auto-generated method stub
		while(true) {

			try {

				String newValue = driveDataSendQueue.take();
				System.out.println("Got new drive data, adding to UnityQueue: "+
				newValue);
				Scanner sf = new Scanner(System.in);
				String input = newValue;
				byte[] buffer = input.getBytes();
				DatagramSocket sck = new DatagramSocket();
				InetAddress address = InetAddress.getByName("Localhost");
				DatagramPacket mypacket = new DatagramPacket(buffer,
				buffer.length, address, 8887);
				sck.send(mypacket);

			} catch (IOException e) {

				// TODO Auto-generated catch block
				e.printStackTrace();

			} catch (InterruptedException e) {

				// TODO Auto-generated catch block
				e.printStackTrace();

			}

		}

	}

}
```

E.5. Java Force Sender

```
package SerialConnector;
import java.io.IOException;
import java.net.DatagramPacket;
import java.net.DatagramSocket;
import java.net.InetAddress;
import java.util.Scanner;
import java.util.concurrent.LinkedBlockingQueue;
import java.util.concurrent.TimeUnit;

public class ForceSender extends Thread {

	private LinkedBlockingQueue<String> forceDataSendQueue;
	public ForceSender() {

		this.forceDataSendQueue = new LinkedBlockingQueue<String>();
```

```
	}
	public void init() {

	}
	public LinkedBlockingQueue<String> getForceDataQueue(){

		return forceDataSendQueue;

	}
	@Override
	public void run() {

		sendForceData();

	}
	private void sendForceData() {

		// TODO Auto-generated method stub
		while(true) {

			try {

				String newValue = forceDataSendQueue.take();
				System.out.println("Got new force data, adding to UnityQueue: "+
				newValue);
				Scanner sf = new Scanner(System.in);
				String input = newValue;
				byte[] buffer = input.getBytes();
				DatagramSocket sck = new DatagramSocket();
				InetAddress address = InetAddress.getByName("Localhost");
				DatagramPacket mypacket = new DatagramPacket(buffer,
				buffer.length, address, 8888);
				sck.send(mypacket);

			} catch (IOException e) {

				// TODO Auto-generated catch block
				e.printStackTrace();

			} catch (InterruptedException e) {

				// TODO Auto-generated catch block
				e.printStackTrace();

			}

		}

	}

}
```