Virtual Reality Rowing

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Abstract

This research focuses on the improvement of rowing technique for beginning rowers. The rowing machine, which is a popular alternative to a real rowing boat, is able to show diverse data about the performance of the rower. It does however not seem to be very engaging for the rower as it does not provide any feedback on technique. The rowing machine also does not provide the same experience as a real rowing boat, meaning the technique learnt on an ergometer is hard to apply in the boat. Without proper coaching, incorrect usage of a rowing machine could lead to injuries and a lack of enjoyment or motivation. For this project, a survey was conducted among student rowers to assess these issues. From this survey, it was clear that the rowing machine lacks feedback on technique, engagement, and differs significantly from a real rowing boat. This project then continued on an existing virtual reality rowing installation which featured feedback on the rowing technique. Competition was added as a game element in order to motivate the rower to perform better. More feedback was added The goal was to create a system where the rower is required to perform well on both technique as well as speed in order to win from a competitor. A user test was conducted to test the effects of competition, feedback, and enjoyment. Due to COVID-19, only four participants were able to help in this research, which means there is no good conclusion, but merely an indication. All participants reacted differently. From the results, it was clear that all participants reacted generally well on the competition and the (positive) feedback. The user interface was not very optimal and can be improved on. Sound also has potential, but needs more immediate and effective sound design. The participants did report that they thoroughly enjoyed the experience and all favored the environment with a combination of technique and performance feedback.

Acknowledgments

First of all, I want to express my gratitude to Robby van Delden, who was my supervisor during this project and helped me tremendously throughout the process, he was always available and provided very valuable feedback. I also want to thank Dees Postma, who was very enthusiastic and critical during discussions.

In addition, I am very thankful about my housemates who have helped me during the testing phase and were able to help me during difficult circumstances during the project.

I want to compliment Koen Vogel and Sascha Bergsma for making such big steps in this project and I am enthusiastic about the future for this project, so I would like to stay a part of it.

Contents

1 Introduction

1.1 Background

The rowing machine, or ergometer, is a very popular machine that is used widely (see figure 1). The machine can be found in every gym and provides good exercise as it is essentially a full-body workout [1]. It is also an important part of the rowing sport, because it is a great alternative as it is flexible and more accessible for coaches to give feedback on their rowers [2].

Figure 1: a Concept 2 rowing machine.

The rowing movement requires correct technique, which is hard to learn. The ergometer gives no feedback on the technical performance of the rower, but only displays real time statistics. The rower himself is not able to determine what is correct or incorrect technique, which makes learning technique quite hard. Bad technique can also result in injury, and this is very common amongst rowers[3]. There is also a difference between learning technique on a rowing machine and in a real rowing boat. A rowing machine is not a very accurate simulation of a boat, which means that rowers who learn technique on a rowing machine have to 're-learn' the technique in the boat.

The novice also needs a goal or motivation in order to do a full exercise on the rowing machine and to return to the machine the next time. the rowing machine does not provide a lot of engagement for the rower, making the exercise probably tedious and less enjoyable. this can mean that the rower has less motivation or drive to perform better.

These problems can be addressed with a coach, but this is not always possible. Often novice rowers train in large groups with big skill differences[2, 8], which means that it is not possible for a coach to give all attention to one person. And of course, during the current COVID-19 pandemic, it is harder for (novice) rowers to train with coaches as there are restrictions.

1.2 Goal

This project is an opportunity to improve the current state of rowing machines by introducing an improved way of learning technique, adding motivation and closing the gap between the experience of a rowing boat and an ergometer.

In this project, the aim is to work with a virtual reality (VR) environment, which entails a headset that can be strapped on and is able to immerse the user into a different environment. Sascha Bergsma's graduation project [8] already developed a virtual reality system that gives feedback on the rower's technique using visuals in VR. Even though the focus of that project was not about engaging rowers, it does provide a good start for a full-fledged training system, which is why it will be used in this project.

There is a lack of engagement currently with the existing rowing machine, and rowers are not able to realize their mistakes during rowing. Gamification could be an approach to address both these problems. By using game elements like competition and rewards, rowers might be more motivated to learn good technique. It is important that rowers learn good technique above speed results. Lastly, it would be very useful if rowers are able to advance on their own by using the system, and are able to apply what they learned correctly in a real rowing boat afterwards.

The rowing machine is a good tool in order to create such a system, because the machine is stationary and it is very easy to track the movements of the different parts of the machine. The rowing movement is also a repetitive motion, which makes it approachable to research.

1.3 Research questions

From the goals stated above, the main research question can be as following:

Main question

"How can beginning rowers be motivated to perform technique better on a rowing machine using game elements in a virtual reality environment?"

Sub-questions

- how enjoyable is rowing on an ergometer compared to real rowing?
- What game elements can motivate rowers to exercise?
- How can ergometer rowing become more engaging?
- How big is the difference between learning technique on the ergometer compared to the boat?

1.4 Overview

These research questions also provide the structure of this research paper. First, the current state of the art and existing works will be discussed, as well as the concept of gamification. In this section, a literature review concerning game elements will be done and a survey is made that addresses some issues discussed earlier, after which the results are highlighted. Afterwards, a user test will be set up, the method of testing will be explained and will be slightly adapted to the COVID-19 pandemic. The results of this test is then discussed, after which the discussion, conclusion and recommendations for future research will follow.

2 State of the Art

in this chapter, the current state of rowing technique, the rowing machine and related work will be discussed.

2.1.1 Rowing technique

The rowing stroke is divided into four parts:

- the catch, which is the beginning of the stroke;
- the drive, which is the motion backwards applying pressure;
- the finish, which is the end of the stroke which leads to the
- recovery; the movement back to the front.

These steps are also depicted below.

Figure 2: the rowing stroke in four phases, performed on an RP3

As highlighted in the article by Sascha Bergsma [8], there are a few common mistakes beginners tend to make. The Royal Dutch rowing association also published a small guide on the beginning errors in rowing [13]. Examples are:

- not pushing enough with the legs at the catch, and immediately tilting the back.
- pulling on the arms; not keeping them stretched and relaxed.
- Missing the catch because of tensity in the arms and back.

Another type of beginning errors that was mentioned by one of the coaches was a wrong order of executing the four parts of the rowing stroke, which leads to incorrect handle heights when recovering.

In case a rower is performing such an error frequently, a coach is able to step in and correct them in three main ways. In a visual way: the coach shows the beginner what they are doing wrong and how it should be done. Auditory: next to the fact that rowers are able to hear errors in the rowing boat, coaches can give extra feedback calls about their technique during a training. Haptic: a coach can also choose to slightly nudge the rower in the right direction, by for example holding a hand out (creating a boundary) behind the ergometer to show the limit of how far the rower can stretch their back.

While there are a lot of common errors among beginner rowers, this project will focus only on the angle of the back (posture), stroke speed and handle height. These errors are very visible and can be tracked and implemented in VR easily compared to other kinds of errors. Especially having a correct handle height can avoid common errors like the wrong order of execution or not pulling the handle in a straight line during the drive.

2.1.2 Ergometer screen

The *Concept 2* rowing machine gives different statistics on-screen while the rower is using it, as seen in figure 3. It can display for example the total time, average speed, current speed, time, a force curve and the stroke rate. This data is being updated after every stroke, allowing the rower to determine their real-time output performance. This is very useful, because it is often regarded as the most important variable for determining learning [5], and the user is able to see their performance.

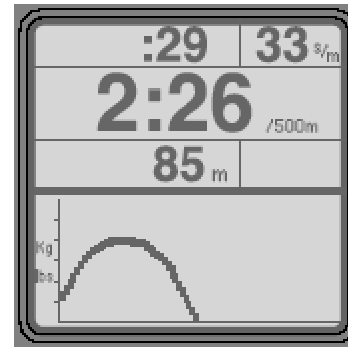

Figure 3: The screen of the Concept 2 ergometer featuring an ideal force curve.

However, the Concept 2 only displays data about the output of the rower. It is not able to show the rower anything technique-related, for example the posture or form. Thus when using an ergometer, coaching or supervision is needed to give feedback on the rower because the ergometer itself cannot do this.

The only statistic that may indicate incorrect technique can be the 'force curve', which is a graph that displays the pulling force of the handle. This curve draws the power on the handle in real-time with the rower. By analyzing the graph, it is possible to find out what may be wrong with the form of the rower during the drive. According to Concept 2, the ideal force curve should represent a smooth round peak, just like in figure 3. If there are multiple peaks or the curve is not smooth, there might be something wrong with the technique of the rower. [15]

2.1.3 Knowledge of results and performance

Knowledge of results (KR) and knowledge of performance (KP) are two kinds of feedback that can be used when learning an exercise as rowing. KR on a rowing machine is simply the different statistics seen on the screen, so these are results only. KP is about the movement itself: the performance, or technique of the user. Often coaches use knowledge of performance in order to learn someone technique. This can be for example: 'the rower bends in too much', or 'the shoulders are tense'. This kind of feedback is currently not featured on the *Concept 2.* It can however be very useful in the case of motor learning, because it is proven to be effective for motor learning in the case of learning repetitive movements and it can prevent injury. [6]

In the article, there is also a comparison between KP and KR with a simple ball throwing study. Though both kinds of feedback are effective in the case of learning a repetitive movement like throwing, KP had better results. the article suggested that KP was more effective and that this kind of feedback could be very useful for athletes, who are learning motor skills or are recovering from a past injury.

Considering the *Concept 2* does not give the user any knowledge of performance, it will be very important to focus on this. Because it is suggested that it has positive effects and coaches often use this method, it may be of great value in this project.

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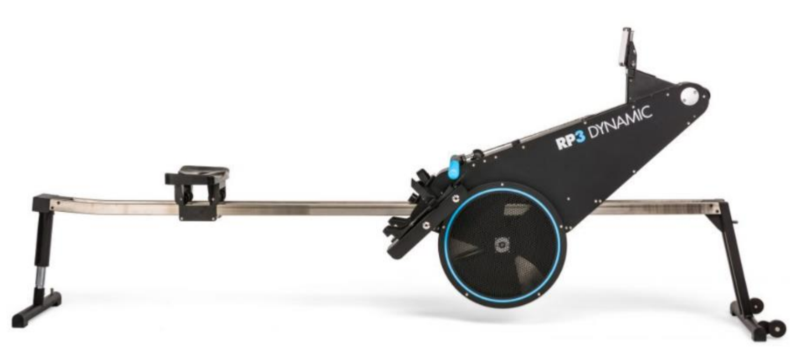


Figure 4: The RowPerfect Dynamic machine

2.1.4 Rowing machine

The type of rowing machine that will be used for the project is an RP3 (RowPerfect) dynamic rowing machine. This machine differs from the standard *Concept 2* because the flywheel also moves over the slidings (see image), creating a more realistic feeling of rowing in a boat. Instead of moving the seat back and forth, the flywheel is pushed away. It also comes with its own software that can be used with a phone and is able to display performance statistics and trainings of the user. This ergometer is often used by the more experienced or professional rowers in the world.

According to the RP3 manufacturer, the machine rewards good technique, and bad technique can be felt.[7] This kind of rowing machine already gives the user more KP, because it indicates when a user does an incorrect movement. This is still an indication though; the user is still not able to dissect what aspect of their movement is wrong. The RP3 will be explored more in the survey later on in this chapter, where rowers have expressed their experience and opinion with the RP3.

Another big advantage of the RP3 is the software that is available. Not only does the machine work with an application that is able to display a lot of data and keep track of training sessions, but it is also possible to connect the machines with one another. There are already a few applications written for the RP3 that are able to analyze trainings of the rower.

2.1.5 Gamification

the term gamification means the “use of game design elements within non-game contexts” (Deterding et al., 2011), so turning a non-game situation into a game. This is done often with the goal of motivating a person to perform a specific behaviour. In this case, it is the rowing exercise that needs to be gamified.

In the article ‘*How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction’,* seven game elements are highlighted that are used commonly in games. These are:

- Points
- Badges
- Leaderboards
- performance graphs
- meaningful stories
- Avatars
- Teammates

Of all these game elements, leaderboards, performance graphs, points and badges are often used to motivate exercise, for example with the app *Strava.* These are all aspects that are used in order to give the user a sense of competition with either themselves or with others. This seems to work; there are already several studies suggesting that this has positive effects. [10, 22, 23]

Competition only works under certain circumstances. [26, 28] It seems to matter whether the opponent is substantially better or worse: if the difference in performance between the user and the opponent is too big, the user will not feel very motivated because the opponent is either unreachable or too easy to defeat. Therefore it is important to find an ideal balance between the user and the opponent.

2.1.6 Existing installations

Row Studio

A special type of software is used for group sessions, called RP3 Studio. This is a software that can combine data of dozens of RP3's at the same time and create a group lesson environment. A good example is the RP3 Rowing gym located in Amsterdam, called RowStudio[1]. Personally I have not been at the studio in Amsterdam, but did participate in one rowing session in Haaksbergen as a test. This is an RP3 exclusive workout that uses the software in an interesting way: they are able to display the total team effort in watts, show real time leaderboards for the top contributing people and show the total distance rowed. The software created a 'team feeling' similar to rowing in a boat together, even though every person has a personal machine, and this experience has left an impression on me about how group trainings on the ergometer can be.

[1] https://rowstudio.nl/

2.2 Related work

Zwift

This is a non-immersive training system that allows athletes to either run or (indoor) bike with others. The system consists of either a treadmill or bike, connected to a screen (see figure 5). The user is able to run just as fast in the game as in real time, and is able to run at certain locations in the game. It uses game elements like points, achievements and leaderboards to keep the athlete motivated to run more often. The user itself also has a (customizable) avatar which is visible on-screen, as well as other friends' avatars. It is possible to program complete trainings either alone or with others and physically run together, and afterwards it gives an overview of the performance. This technology is especially useful when athletes are not able to train together physically but want to feel like they are training together with others.

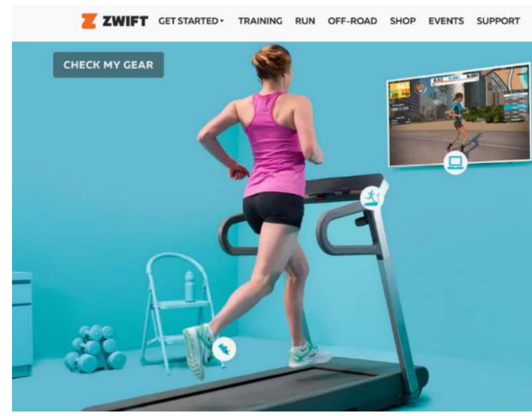


Figure 5: the Zwift application

BlueGoji

This is another type of virtual training technology. The goal of this installation is to help people to get healthier by combining training with entertainment. This running installation is either immersive (with a VR headset) or non-immersive (a computer screen) and is similar to Zwift: it is possible to plan trainings and train together with others. It is possible to use a treadmill like in figure 6. The company is also invested in the concept of 'e-sports', which in this case means to professionally compete with other athletes on the treadmill, virtually. There are already tournaments organized which also featured this piece of technology.[10] RP3 is currently in contact with BlueGoji to make a similar system on a rowing machine.

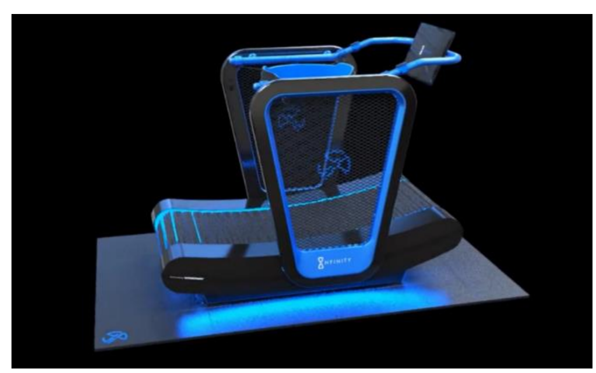


Figure 6: The blueGoji treadmill with screen

2.3 Survey

2.3.1 Motivation

As mentioned in the introduction, the Concept 2 rowing machine does probably not provide enough engagement for rowers. This is presumed because of the lack of feedback on the ergometer screen, but also out of personal experience. However, this needs to be confirmed in order to say so with confidence. That is why it is important to look at the current experience of rowing on an ergometer by various types of rowers in order to make a fair assessment.

Not only is it important to be aware of the ergometering experience, but also the real rowing experience. How do rowers feel about rowing in general, and how much of a difference is there between ergometer rowing and real rowing? In case participants reply relatively negative towards real on-water rowing, then maybe there needs to be a design solution for this as well.

The next question that needs to be asked is the compared experience of the rowing itself to ergometering. Is a rowing machine truly a good alternative to real rowing? Of course, the rowing machine is not a 'rowing boat simulator', but merely an alternative machine that can be used by rowers in the case of bad weather or developing endurance. However, if the difference in feeling between real rowing and a rowing machine is too big, then this could potentially mean that learning rowing technique on an ergometer has little effect on improvement when the rower applies this technique afterwards in a rowing boat.

As mentioned previously, rowing technique is challenging to master and very precise. However, the screen on the *Concept 2* is not designed to help the rower with their technique. This can be seen by the metrics on the screen: it only displays metrics like the speed, time and distance of the rower, but nothing about posture, sliding speed or handle height. In order for a rower to improve their rowing abilities and increase their performance, correct technique is quite important. This technique support is clearly lacking on the ergometer, but the opinion and experience of rowers needs to be taken into account in order to choose the best solution. It is therefore important to ask confirmation on whether the rowing machine provides technique feedback, and if not, what kind of feedback the rowers would like to see.

Furthermore, The *Concept 2* is a widely used rowing machine as both a training machine and an official racing machine. It is known that this is the standard, popular product compared to the RP3. This could be because of multiple reasons:

- The *RP3* is almost three times more expensive than the *Concept 2.* The price of an *RP3* starts from $2,900 while the *Concept 2* is around $1,000.
- Almost all official indoor racing events are held on a Concept 2.
- RP3 is a more delicate machine and targeted towards more advanced rowers.

However, the RP3 Dynamic is gaining popularity, especially amongst the more elite rowers of the world. The difference in machines lies in the boat feeling with the dynamic model: the rowing feels more realistic on a dynamic machine compared to the static models. In any case, the demand for RP3 seems to have grown over the past years because of this. If it truly creates a better rowing experience for rowers, it seems like every rowing association should own these machines, but this is not the case for many. It is therefore important to find out if there is a demand, and why or why not.

How is the survey made?

The survey will be targeted towards the local student rowing association based in Enschede, The Netherlands, named "*D.R.V. Euros".* This association has more than 350 members with all different kinds of rowing experience. The survey itself will be shared over a mailing list, which consists of more than 100 members. the full list of questions is found in appendix B.

Enjoyment

Measuring enjoyment needs to be as unbiased and reliable as possible. Therefore it is wise to find an approved questionnaire that can accurately assess enjoyment from participants. The questionnaire used in the survey is the *Groningen Enjoyment Questionnaire* [11], which uses ten questions. Because the enjoyment rowing on an ergometer is compared with real-life rowing, the questionnaire will be asked twice and randomized in order. The questions will be adapted as much as possible to the original questions in order to fit the rowing theme. For example, possible questions from the questionnaire are:

"I feel relaxed when I'm doing leasure-time physical activities." Or: "I like being physically active."

To transform these questions in a rowing setting, the "leasure-time physical activity" will be replaced with "rowing boat activity" or "ergometer activity" in order for the questions to remain as similar to the original questions. The paper also recommends using a five-point Likert scale for the questions.

After the Likert questions, an open question will be asked after the ergometer and rowing boat scenario, which asks what makes that particular experience fun. This way, the motivation behind the rowers might be uncovered, and possible design solutions may come forth.

The survey will be sent out twice, because of difficulties with randomizing the order of the first part of the questionnaire regarding enjoyment. Enjoyment is very hard to research and bias could happen in the situation where the first question influences the second. In this case, it could be that asking about on-water rowing first could cause the responses after about ergometer rowing to turn up more negatively because the respondent compares an expectedly more fun activity with expected less fun activities. Because of this, the results may be slightly biased.

Realism

The next question will be about whether rowing on an ergometer is comparable to on-water rowing. Therefore it is necessary to use at least six questions. Six is a reliable amount of questions, because in the case one question has unusual responses, there are still five more questions that can support the response, which still makes the outcome somewhat reliable.

the goal of these questions is to find a big difference in experience between the rowing boat and an ergometer, which is why questions will be asked similar to "If I can row well on an ergometer, that means I can also row well in the boat." This way, a gap between the machine and the boat might be uncovered as well as the experience and opinion of the rower on this. This section uses a five-point Likert scale section.

Technique and data feedback

The rowing machine display only shows metrics about the speed, power or distance of the rower and no metrics about the technique or performance of the rower. However, it is necessary to research if rowers experience this as well. They will be asked if the rowing machine gives enough data about their technique and about their performance. In this section, again six similar questions will be asked in separate questions in order to compare results. However, for this question a seven-point Likert scale will be used, because these questions can reveal more subtle differences between questions.

Concept 2 versus RP3

This last part of the survey will ask rowers about their rowing experiences on both machines and which machine they prefer. This will give answer to the question of which machine is more popular, and which delivers a better experience.

First, the rowing experiences on both machines will be asked. After, there will be questions regarding preference to one of the machines in different situations, for example learning technique or endurance tests. Then, the participant has to choose their ergometer preference in case of a lockdown scenario.

These questions are beneficial in order to find out what rowers are used to training on, and what they actually prefer. However, we do need to keep in mind that a lot of these rowers have little to no experience on a dynamic rowing machine, because these were until recently not present at the rowing association.

Other information

It will be interesting to look at how different types of rowers answer the questions, which is why in the beginning of the form, the type of rower, years of experience and rowing association is being asked. Other than that, gender, age and current working status is asked as well. The questionnaire remains anonymous, and so it should not possible to trace back identities based off of the personal information selected in the first section.

2.3.2 Results

In total, there were 61 responses from the mailing list. After sending the survey and communicating with some members, it seemed that for some members of the list, the mail ended up in their spam email box, which means there were less people reached than intended.

A good balance of different types of rowers have responded. This can be seen in table 5 on the right. The only group that may have slight underrepresentation is the Cox type (the people who steer the boats), which are a total of three. What is also important is a fair amount of beginning rowers have responded, because these are the type of people this project is targeted towards.

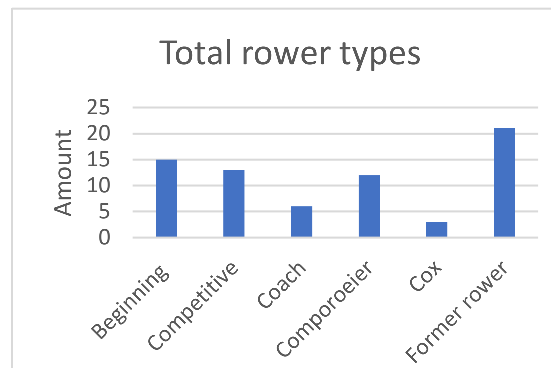


Table 1: The different types of rowers who participated in the survey.

For the questions about enjoyment and the comparison with data and performance, a significance test will be used in order to prove a significant difference between the two answers. There has been a lot of debate in the world of statistics around Likert-scale questions, because this type of data is seen as ordinal, which means that the data is not assumed to be normally distributed. As such, parametric tests like T-tests can probably not be used, and instead non-parametric tests like the Mann-Whitney U test (Wilcoxon rank-sum test) are advised. Regarding the debate, there is one study [12] however that provides evidence that the difference is not large: the difference in statistical power is nearly identical, and the error rates for both kinds of tests are very similar as well. If there is a statistical difference between to populations, both kinds of tests will be able to prove this.

For this survey, the goal is simply to test significance between two datasets. Because the only type of action will be the comparison of means and a simple t-test is very likely able to prove significance as well as other non-parametric tests, the choice of test will be the parametric t-test. A full study on the use of non-parametric tests in the case of Likert-type questions might be out of scope for this project, because this requires a lot of background research on the ongoing discussion.

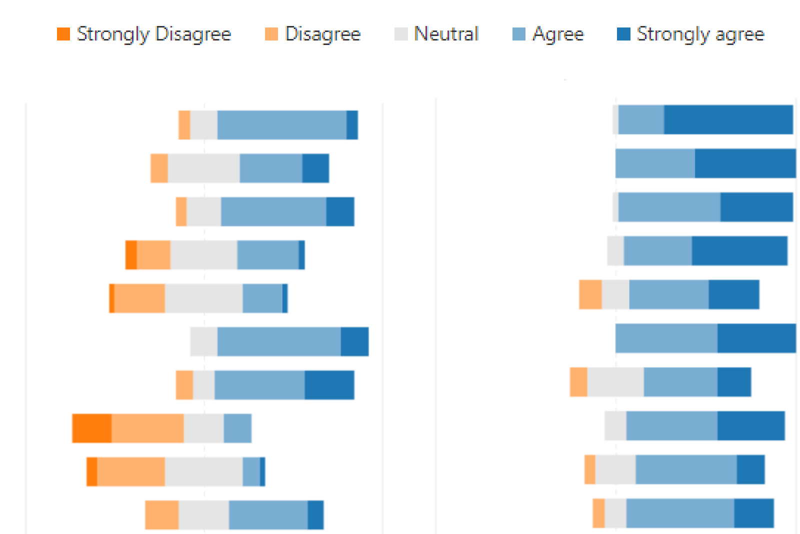


Figure 7: results from the survey about enjoyment. Left: ergometer rowing, Right: on-water rowing.

Enjoyment

In the first part of the survey, the enjoyment of ergometer rowing compared to on-water rowing is asked. The results of the two questions are seen in figure 7. It is very clear that the answers towards real rowing are much more positive compared to ergometer rowing. This can be seen from the more positive replies on the right: almost all respondents agreed to the questions.

First, a Cronbach-Alpha test is done, to assess the reliability of the results. The function of such a test is to check whether all questions ask or research the same topic, and therefore how reliable results are that come out of it. For example: if the reliability is low, then that means that questions could be poorly worded or the questions are (accidentally) researching another topic at the same time. The value that comes out of the test is between 0 and 1, and 1 being most reliable. From this test done in excel, a reliability of 0.732 is calculated. This is in the 'acceptable' category, but does not completely resemble the found value from the *Groningen enjoyment questionnaire*, which presents a value of 0.84. [11]

vragen	20
sum var	6.97168
var sums	21.80371
0.732884	

Figure 8: results from the Cronbach-Alpha test.

The means of all results are first calculated by giving the answers a value from one to five, according to the Likert scale, so 'Strongly Disagree' would get a value of 1, and likewise, "Strongly Agree" would receive a 5. The mean of the results per question of both surveys will be combined and then tested on significance with a simple t-test in Excel. There are two times ten questions, so the total dataset is 20.

By using the parametric approach, we assume that the data is normally distributed. But as a check, the Kolmogorov-Smirnov Test of Normality will be used to test the two datasets on normality.

Distribution Summary

Count : 20

Mean: 3.78438

Median: 3.859375

Standard Deviation: 0.639864

Skewness: -0.785586

Kurtosis: 0.184556

Figure 9: Results from the Kolmogorov-Smirnov test.

To calculate this test, an online calculator is used[2]. As seen in the distribution summary in figure 9, the skewness is slightly to the left, and the Kurtosis is close to zero. The result of the test statistic (D) turns out to be .148, and the p-value .71946, which is bigger than 0.05, which means the null hypothesis in this case (H_0: the distribution is normal) is not rejected. This means that the data seems to be normally distributed.

The t-test can be performed either by assuming equal variances between data sets, or by assuming non-equal variances. By using the Excel statistical tools, it is found that the p-value is 0.02 < 0.05, so the variance can be assumed not equal. See figure 10.

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	3.417619	4.161584
Variance	0.368572	0.148186
Observatic	20	20
df	19	19
F	2.487218	
P(F<=f) on	0.026932	
F Critical o	2.168252	

Figure 10: Results from the F-test on variances.

In Excel it is also possible to do a t-test, but this is only possible for two-tailed types. However, this can be solved by dividing the t statistic by two. after performing the test, it is clear that the t statistic ("t Stat" in figure 11) is -4.6, so dividing by two gives us -2,314. The critical t value is 2.03.

-2.314 < -2.03, which means the t statistic lies on the left side of the distribution, meaning the difference between the data sets is just significant.

This might imply that the participants of the survey truly find rowing in a real boat more enjoyable than ergometer rowing. However, the statistic was very close to the critical point which could mean that there is not a very extreme significance.

1	t-Test: Two-Sample Assuming Unequal Variances		
2			
3		*Variable 1*	*Variable 2*
4	Mean	3.417619	4.161584
5	Variance	0.368572	0.148186
6	Observatic	20	20
7	Hypothesi:	0	
8	df	32	
9	t Stat	-4.62833	
10	P(T<=t) on	2.92E-05	
11	t Critical o	1.693889	
12	P(T<=t) tw	5.83E-05	
13	t Critical tv	2.036933	

Figure 11: Results from the t-test.

[2] https://www.socscistatistics.com/tests/kolmogorov/default.aspx

Open questions

For rowing on an ergometer and in a real boat, there was an open (optional) question about why this type of training experience is fun for the rower. Even though the question was optional, a big percentage of participants filled in the questions.

Regarding on water rowing, the most frequent answers were:

- The environment on the water is often mentioned as a contributing factor. People seem to enjoy rowing in nature.
- Teamwork is mentioned often also. The feeling of rowing together and making a team effort is what a lot of participants mentioned.
- The feeling of going fast or pushing the boat through the water is also a recurring statement.

Regarding ergometer rowing, some of the positive mentions are:

- The ability to see improvement after each training;
- The data on the screen motivates the rower to put in more effort;
- The feeling of accomplishment when an improvement is noticed.

Difference between a rowing boat and an ergometer

In this section, questions regarding the difference of experience between boat and ergometer are asked. These are questions that ask whether learning new technique on an ergometer can also be applied in the boat, and whether ergometer is a good replacement for a real rowing boat.

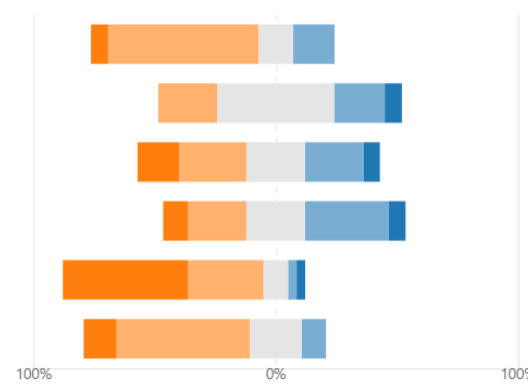


Figure 12: The results from the survey on the difference between a boat and an ergometer.

As seen from figure 12, generally the responses are somewhat negative. The third and fourth question are interesting to look at, because here the opinion of each participant seemed to differ. The questions were about how good of a replacement an ergometer is for a real boat, and how well the participant can learn from rowing on an ergometer, respectively. It seems that there are mixed feelings about these questions, but these could come forward because of the previous question, which asked about the preferred ergometer. In the case of an RP3, it seems more logical to reply more positively towards these two questions. However, from the individual answers, there is no clear trend that the replies from people who prefer an RP3 have replied more positively overall.

From the open questions, which asked about the advantages of rowing and ergometer rowing, a few interesting points came forward:

- A rowing boat is considered more engaging, because there is feedback when the rower is doing it wrong. These hints can be balancing problems, or a feeling of the blades of an oar that 'catch' the water. Especially this last feeling is missing on the ergometer. Another engaging part of rowing seems to be team effort, which means moving as a whole. This is also not featured on an ergometer, so this is only found in a boat.
- An ergometer is more useful when the rower wants to eliminate external factors to focus on only one. External factors that are named are wind, waves, catching the blade and balance. It is also something that can 'always' be done, because it does not require preparation, e.g. putting the boat in the water, great weather circumstances, or a certain amount of people to be present.
- Something that stood out was the fact that a lot of responses mention learning technique on an ergometer as an advantage. One participant mentioned that it is easy to get used to the basic movement

of rowing on an ergometer, because it is possible to repeat it well a lot of times without having external factors that might distract the rower. But even though it seems to happen that a lot of rowers learn technique partly on an ergometer, still the responses on this question seem quite negative, which maybe suggests that it is not very effective.

<u>Data versus performance</u>

Because of the very similar outcomes on both versions of the survey, only one of each question type will be displayed here.

In this question, a seven-point Likert scale is used, and because of this it is possible to see more subtle differences in responses (see figure 13). The results about the feedback on performance seem to be generally more negative compared to the data feedback question. Of course, this difference in response was already suspected as the ergometer screen only provides data metrics. Especially the last question, which asks about whether the machine can help the rower learn how to row with only the ergometer (without coaching), the result seem more negative.

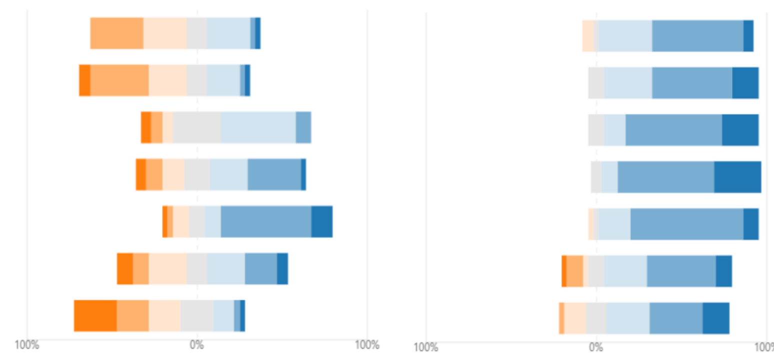


Figure 13: results from the survey about feedback. Left: feedback on technique, right: feedback on performance

The results about technique do seem to differ very much from the questions about data, but there are potential outliers in the dataset. There are a few respondents who clicked ‘agree’ or ‘strongly agree’ on every question, which could mean that the entries made the chart slightly more skew. However, it is still important to statistically find out if there is a significant difference between the datasets.

First, it is important to find out whether all questions are related to each other and accurately measure the opinion on the same topic. To test out the reliability of the two datasets, the data from both questionnaires are combined and both the questions about technique and result-based tested with a Cronbach-Alpha test (see image 14). Interestingly enough, the value for the datasets are quite different, as seen in figure 10. Generally speaking, a score of about 0.6 - 0.7 is acceptable in terms of reliability, while 0.8 or greater means a very good level. [14] The questions that ask about possible technique feedback receive a higher reliability than the result-based questions. this could have a number of reasons, for example bad wording of questions. considering the only difference the two question sets are, this could very well be the problem, for example in the text: ‘data on results’. This could be slightly confusing to the respondent.

technique	
questions	7
sum of vai	16.8729
var scores	56.5155
	0.81835

results	
questions	7
sum of vai	10.2849
var scores	23.2034
0.64954	

Figure 14: Results from the Cronbach-Alpha test.

In this case it is still assumed that the data is normally distributed, but the normality is checked here as well. First, the mean is calculated from the results of every answer, which after are used in the Kolmogorov-Smirnov test (see figure 15). This resulted in a p-value of 0.87377, which is bigger than 0.05, so the null hypothesis is not rejected and the data can be assumed normal.

Distribution Summary

Count : 14

Mean: 4.60187

Median: 4.819672

Standard Deviation: 1.07594

Skewness: -0.386467

Kurtosis: -1.170984

Figure 15: Results from the Kolmogorov-Smirnov test.

Then, an F-test was conducted to check for variances. The results of this test, performed in excel, are seen in figure 17. By using the excel statistics tool, the p-value was found to be 0.122, which is bigger than 0.05. That means that null hypothesis (H_0: the variances are equal) are not rejected, and equal variances can be assumed.

F-Test Two-Sample for Variances		
	Results	*Technique*
Mean	5.44262	3.76112
Variance	0.22942	0.62948
Observatic	7	7
df	6	6
F	0.36446	
P(F<=f) on	0.12238	
F Critical o	0.23343	

Figure 16: Results from the F-test for variances.

Finally, the t-test is performed, but this time assuming equal variances. In figure 16, the T statistic seems to be 4.8 (but divided by two, so 2.4), while the critical point of T is at 2.18. 2.4 > 2.18, so the null hypothesis can be rejected meaning there is a strong possibility that the data sets differ significantly.

t-Test: Two-Sample Assuming Equal Variances		
	Results	*erformance*
Mean	5.442623	3.761124
Variance	0.229419	0.629477
Observatic	7	7
Pooled Var	0.429448	
Hypothesi:	0	
df	12	
t Stat	4.800376	
P(T<=t) on	0.000217	
t Critical o	1.782288	
P(T<=t) tw	0.000433	
t Critical tv	2.178813	

Figure 17: outcome of the t-test, assuming equal variances.

Furthermore, the next question was about which metrics are used. In the bar chart in figure 18, which has similar outcomes to the other version of the survey, it is clear that the most used metrics compared to others are the current and average pace per 500 meters, the stroke rate, elapsed/remaining time or distance and the force curve. Noticeably, the kcal burned option has never been selected in both surveys. These are coincidentally also all metrics that can be displayed at once on one screen.

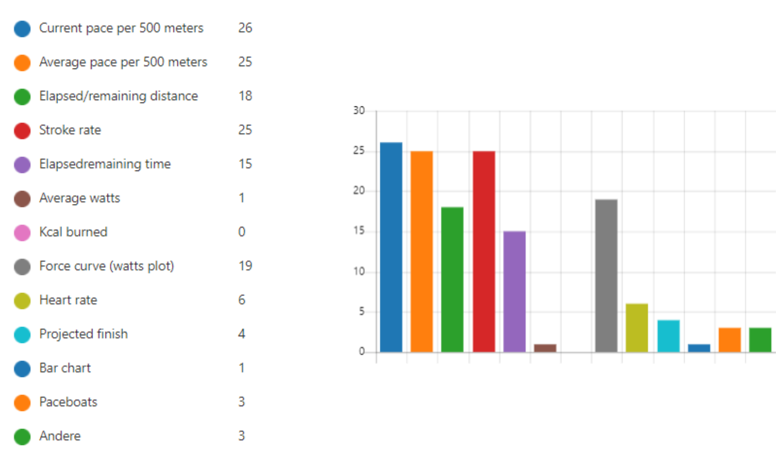


Figure 18: A bar chart representing the most used types of data on a rowing machine.

Afterwards, an open question was asked: “What kind of data would you like to see on your screen other than the data that is already presented?”. The goal of this question was to create a brainstorm for design ideas and to grasp an idea of what rowers would maybe like to see in the future.

The responses for this question are summarized:

- The most popular request was feedback on posture or handle height;
- According to the respondents, there is no feedback on the catch (beginning) of the stroke;
- Feedback on balance of some sort;
- A leaderboard.

Comparison Concept 2 and RP3

in this last part of the survey, the goal was to uncover the amount of experience the participants have on both rowing machines, and to find out which machine they prefer and why. the expectation of results for these questions will be in favour of the RP3 machine, but maybe this will differ between other types of rowers.

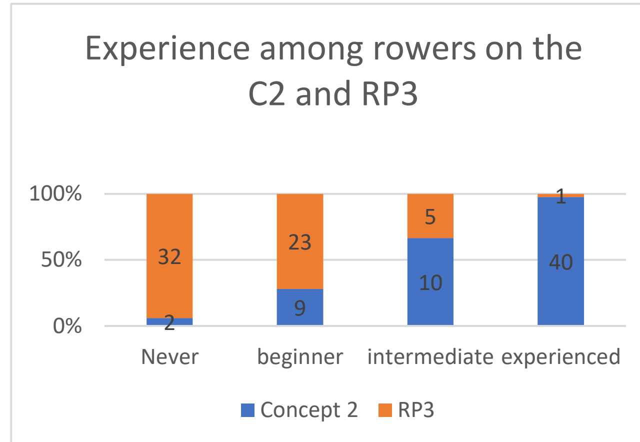


Table 2: The experience of a rower on both C2 and RP3.

The first questions ask about the total experience on both the *Concept 2* as well as the *RP3* in intervals: have they never used the machine, a maximum of 10 or 50 trainings, or even more? In table 2, the distribution is clear: a lot of respondents have rowed significantly more on the Concept 2 than the RP3. Only one person seems so be experienced with the RP3, but this is also a competitive experienced rower. This means that the biggest part of rowers are used to rowing on a Concept 2.

The next four questions ask for each machine: 1) whether they are used to it. 2) if they prefer this machine for learning technique. 3) If they prefer it for tests or trials. 4) if they prefer it for real races. Results can be seen in the image below, with left being RP3 and right Concept 2. The results on this are not out of place: it seems that the RP3 is chosen slightly more often for learning technique, and way less for the other questions.

From these results visualized in figure 19, it seems as if a lot of people do like the RP3 machine, but maybe are not yet willing to test themselves on it yet. The dynamic machine is recognized a little as being more optimal for learning technique, but is not yet very popular.

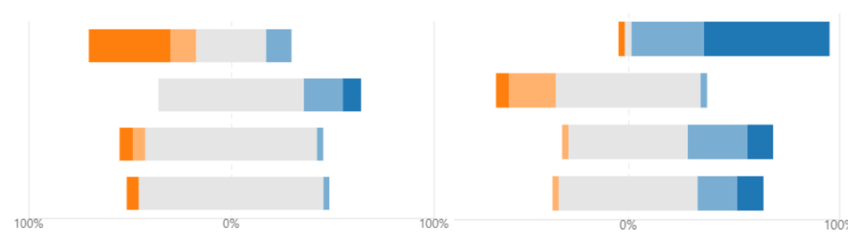


Figure 19: what training is preferred on which machine. Left: RP3, right: Concept 2.

This can be seen in the next question as well: does the RP3 feel more like a rowing boat than the Concept 2?

In both surveys, there seemed to be a general consensus that the RP3 does in fact feel more realistic, which can be seen in figure 20. Though it is visible that a lot of responses were in the 'neutral' category compared to the other Likert-scale questions. This could be happening because of the lack of experience from a lot of participants, which prompted them to answer 'Neutral', but could then probably also mean 'I don't know'.

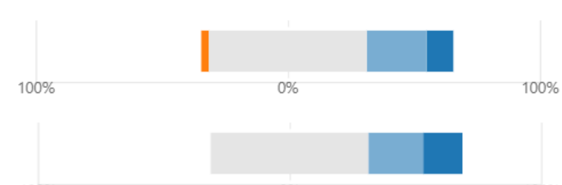


Figure 20: results point to better realism on the RP3.

Finally, the last question asked which machine would be preferred. In total, 19 people chose the RP3 as preferred method. Even though the biggest part of this group are used to rowing on a Concept 2, still nearly a third would prefer the RP3. But, this is still a rather small group. In the open question following this one, rowers can tell their motivation behind their choice. The biggest issue that came up is the fact that a lot of them are used to using Concept 2 and have never tried and RP3. This is why two thirds of the group still chose the Concept 2 machine.

2.3.3 Conclusion

Enjoyment

The statistics and show that rowers enjoy the ergometer less than a real rowing boat. From the open questions, it was possible to deduce that rowers like rowing through scenery, enjoy rowing together and view an ergometer generally as replacement during extreme weather or a way to build endurance.

Difference rowing boat and ergometer

Out of the survey, it is clearly visible that there exists a gap between the rowing boat and ergometer. Even though a lot of technique is learnt on it, the effect is not very strong, because the results are skewed negatively. From the open questions it was possible to deduce that there is engagement missing while rowing on a rowing machine. These could be about the catch, recovery or balance during a stroke.

Data and performance

Participants generally seem to agree that the rowing machine gives off a lot of information about the performance of the rower, in the form of speed, power or distance. Additionally, the data that is being used the most is the average and real split (minutes per 500 meter), stroke rate, elapsed or remaining time/distance and the force curve. However, the results are more negative about how much the rowing machine helps the rower develop good technique.

Concept 2 versus RP3

The Concept 2 is a very popular machine, this can be seen in the results. The biggest part of the respondents are used to using a Concept 2, and only a small amount of people have considerate experience with the RP3. The Concept 2 is still preferred for performing tests, trials and real races, but there seems to be a general consensus that the RP3 might help more in learning technique. This is seen by the fact that there is a much more positive attitude towards the realistic feeling of the dynamic machine, as well as the fact that generally responses were positive about using the RP3 for learning technique. In total, almost a third of the respondents indicated that they would prefer the RP3 over the Concept 2, but because the biggest part of the respondents have never used an RP3, the preference for a machine is still for two-thirds a Concept 2. Most reasoned that the Concept 2 is the machine they are used to.

2.4 Gamification in sports – a literature review

Introduction

Virtual reality is a new technology that allows the user to be immersed in any situation imaginable because it gives the user a 360 degrees view of their video game. It is also often used for sports and gives the player the possibility of simulating their own trainings [16]. This can be extremely useful for learning technique, for making the exercise more fun or to let the user experience the environment. These kinds of simulations are called 'exergames' and essentially mean that exercise is involved with certain game aspects to immerse the player. This can be especially useful to motivate the user. In this literature review, the scope of these exergames will be mostly about the rowing exercise, which is an endurance sport which requires both physical strength and endurance [1]. Ergometers, which are indoor rowing devices, are especially popular during cold seasons or when regular trainings in boats are not possible. Rowing is also rather repetitive which means that trainings could become tedious or cause injury as well [3, 22].

A lot of research is already conducted about combining rowing exercises with virtual reality and game elements, or exergames. There are several studies that suggest virtual reality exergames can enhance motivation and performance [22, 23] This 'gamification' of rowing is quite relevant to this research because it can make us understand how different game aspects can help motivate, this is why a literature review will be conducted about the research that has been done for exercising with gamification elements. This also is in line with the graduation project, which researches the best way to motivate beginning rowers to learn rowing technique. Particularly articles that cover the different gamification elements and which ones work the best for the user's motivation are interesting to look at. The research question for this literature review will be:

<u>"How can game elements can be used in order to motivate people to exercise?"</u>

In order to answer this question, it is particularly important to find out:

- What kind of game elements are used in different articles;
- What part(s) contribute to the motivation of the participants.

As this has been said at the beginning, rowing could become tedious, and from personal expertise, the technique is quite challenging to learn. This is why the exercise needs gamification: it can help beginning athletes learn technique and keep exercising. It will be interesting to research how gamification can be implemented to motivate the user to perform better.

In this literature review, all sources will be compared using the concept matrix. The goal of this review is to assess which gamification methods can be used to make the users perform better. Firstly, the two game elements that are most important in the literature will be highlighted further and discussed. Secondly, the types of implementations of game elements will be stated and compared. Then, in the discussion the two elements will be discussed to find out what parts of the implementation motivate their participants the most. Finally, there will be a conclusion and recommendations.

Explanation of game elements

In all articles, there seem to be two game elements that have been used in order to test participants' motivation. These are competition with others and progress of the user himself.

Competition

This form of a game element is used in various ways. Competition in these articles refers to a situation in which the participant of the research needs (or feels the need) to compete against other participants or computer-based opponents. In one article [29], this is realized through an activity app which monitors the participant. In this app, the performance of the participant is tracked and compared to others, which all participants are able to see in the form of a list or leaderboard. Similarly, [31] also created such a leaderboard by making an application that shows all users the wins and losses of every tennis match they play as well as a leaderboard of these players.

In the rowing setups using Virtual Reality, each setup the focus was mainly on competition. In these studies, there were multiple approaches to find out whether on-screen competition, whether it be real or a computer-based opponent, might help the user perform better. This setup might draw out the competitive drive of the participant by trying to 'win'. One article [22] used a simple approach: the opponents which

were displayed on-screen had a random speed, similarly to [26], but used computer-based opponents as well but set the speed to slightly faster compared to the user. Another [32] used this method as well but convinced their participants they were rowing against another teammate. This might provoke the participants to perform even better.

Personal progress

The main purpose of this function for an application is storing data about the performance of the user and giving an indication of how 'fit' or active that person is. There are different ways to approach this kind of feedback. For example, an application combined with a smart watch is used that collects heart rate data and gives feedback on the intensity of the training of users. [21] This is a very popular application model: the app used in the research from [30] has the same mechanic, and it also appears in one of the most popular tracking apps available, Strava[3]. It is also possible to find an overview of all trainings and general statistics of the user concerning his fitness. The benefit of such an app is that the user has a good overview of his performance and fitness and might reflect on his behavior or change it. Another approach is using a point system and leveling, which means that the user is able to collect points based on their performance and is able to 'level up' after a certain amount of points has been reached. This is able to let their users feel like they are partaking in a game by letting them see a progress bar and points needed to achieve a new 'level'. [19]

Implementation of game elements

There are eight articles in total that showed competition and self-progress as a motivation for participants of the research. In the case of studies with tracking apps, there were different approaches in order to motivate their users.

In two articles[19, 27], for example the 'leveling' system was used. This method was combined with a leaderboard in order to implement competition. From interviews beforehand and afterwards, participants seemed very positive about these elements on the app and considerably helped them to be motivated. Participants also found themselves having more fun during exercise. These results are similar to [29]. In this study, users were given the app for a certain time period and were interviewed after. These users reported that they were positive about the self-tracking system within the app. Notably the comparison of performance between sports and the visual overview of the app has been reported as helpful. This application also had a social page which simply featured other people's workouts. In the interviews some of the users reported that because of this, they felt peer pressure to exercise more often. There was only one study that did not use this competition element [21]. In this study, an app was used that only had self-tracking features very similar to [29], however it only missed the social function in the app. During this study, there was no significant difference in performance or frequency of exercise. It was noted by participants that the overview of the application was very insightful about their health, but did not change their exercise behavior considerably.

Considering the other setups with rowing, only competition seems to be the game element that was used. This was in the form of another boat in-game which the participant was able to see. It was found from the performance metrics of the user (e.g. speed, power, distance and heart rate) that in the case the competitor's speed was either randomly determined [22] or slightly faster compared to the participant, [26, 32] The participant still performed better compared to a situation without competition. All setups also used a virtual reality headmount, which also

[3] *https://www.strava.com/*

contributed to the motivation of the user. One research paper [32] demonstrated this with their three performance tests which consisted of a participating group without VR, one with VR only and one VR combined with competition. From the performance statistics of the user, it was clear that the VR setup combined with competition was the best motivator for the rower, but the users with only the VR set also had significant improvement compared to the group without it. Additionally, participants of the VR and competition combination reported not giving significantly more effort for the exercise, while their measured heart rate and rowing stroke rate were statistically higher. A similar rowing setup [22] compared to this graduation project, also researched the perceived fun of participants. From surveys it was determined this perception of fun was improved significantly, which corresponds to similar enjoyment questionnaire results from the other virtual rowing studies used.

Discussion

The personal progress implementation only occurred in the papers with mobile applications. The feedback on different applications about this element was very positive, however it is not clear whether it really motivates users to exercise

more frequently. For example, [21], who solely tested the self-tracking feature, found that using only a self-tracking system like an application with a watch did not significantly contribute to a more active lifestyle. Additionally, [32] showed that whilst only having technique feedback already helped participants to perform better, the difference was still not as significant as using competition. This may indicate that personal progress might not be enough in order to motivate users the most and should maybe be combined with other game elements.

Furthermore, in the studies concerning the applications, the part that motivated their users the most seemed to be competition, as this was perceived as positive feedback or ‘peer pressure’, and was reported to help participants exercise more frequently or longer. This is seen in the other articles with a tracking application which also used competition, as the results there are significantly positive as well. The research stated before [28] may even slightly support this finding: this research was the only one out of five papers that researched fitness apps without competition and measured no positive difference in duration or frequency of exercise. This is only one source however, so more research needs to be done to discuss this.

Lastly, From the articles that concerned rowing, the situation with competition present had the most effect on the performance of the participant as seen from the performance metrics of the participant. An interesting find from one of the surveys also revealed that apart from competition, the users also felt more connected and motivated by seeing their friends’ performances. Even though it does seem to be generally effective, there was one article [26] that highlights that this differs per situation. This research also had positive results by combining competition and virtual reality, however this depended on the performance of the opponents. In the case that the competition is too difficult to compete against, the performance of the participant drops. This is not a particularly new phenomenon: it was also described by [28]: if the difference between the user and the opponent is too big, this can be demotivating for the player. For example, this could be the case when the opponent is too far ahead.

Conclusion and recommendations

The aim of this literature review is to research different approaches to gamification and to find out which method is effective. This was done by comparing articles that used a gamification approach with sports, and afterwards discuss the results.

In all research concerning motivation related to sports, competition was the most common tested variable. It seems to be a very motivating factor with the tracking applications as well as the VR rowing machine setups. This is seen by monitoring the frequency, distance and time spent with exercise as well as surveys and monitoring the person. In all tests, the participants scored higher on physical level and performance when they had an opponent or different participant close by. From these results, it is therefore possible to assume that competition is a good approach for motivating people to exercise. However this depends on the situation of competition, and game developers should be aware of the possible impact of their design when using competitive elements such as leaderboards.

However, there were limitations towards this review. First of all, most of the articles that were compared often used competition together with self-progress as a means of researching. Because of this, there is not a lot of ground to argue about the effects of self-progress alone, because this is not separately tested. There was only one article that used this idea, but this might not be enough to assess a conclusion. Second, there were only a few selected articles to compare from, which might not be enough to accurately describe a well-grounded conclusion. More articles would be required, possibly also comparing different fields of exergames apart from sports. Because this GP is about rowing, this was also the focus for articles. But because the implementation of game elements in sports is not exclusive to rowing only, it would be useful to research this about other sports as well. Lastly, this research was conducted by only one researcher, which could make this article unreliable. More researchers would need to review this article in order for it to be more credible.

3. Method

Creative Technology Design Process

A relevant guideline for ideating and creating a design is the *Creative Technology Design Process*. This design method came forth out of observation from projects out of the Creative Technology curriculum and can help students in their design process, planning, implementation and documentation. Because the focus of the Creative Technology bachelor is about using technology in order to improve lives of people, and this project is a method to improve the lifestyle for anyone who wants to learn how to row, this design process seems fitting to use.

The process consists of four phases and starts very broad, to which it narrows down further along the process. Each phase has an internal cycle that can be followed in any order, as seen in figure 21.

The first phase is Ideation, which is the divergent phase of the process. Here, the student will come up with a design question, research their topic and brainstorm about possible ideas. The second phase 'specification' often consists of narrowing down possible solutions and a start on working them out. Realization is the third phase and this means realizing or producing one or more prototypes. The last phase is evaluation, which means mostly (user) testing and reflecting on the design.

In short, the design process has different phases which are either diverging or converging, and serve as a part of a clear design flow that can be used in this project. Here, the ideation phase will be covered in the first two chapters, and in chapters four to six, the phases specification, realization and evaluation respectively will be used.

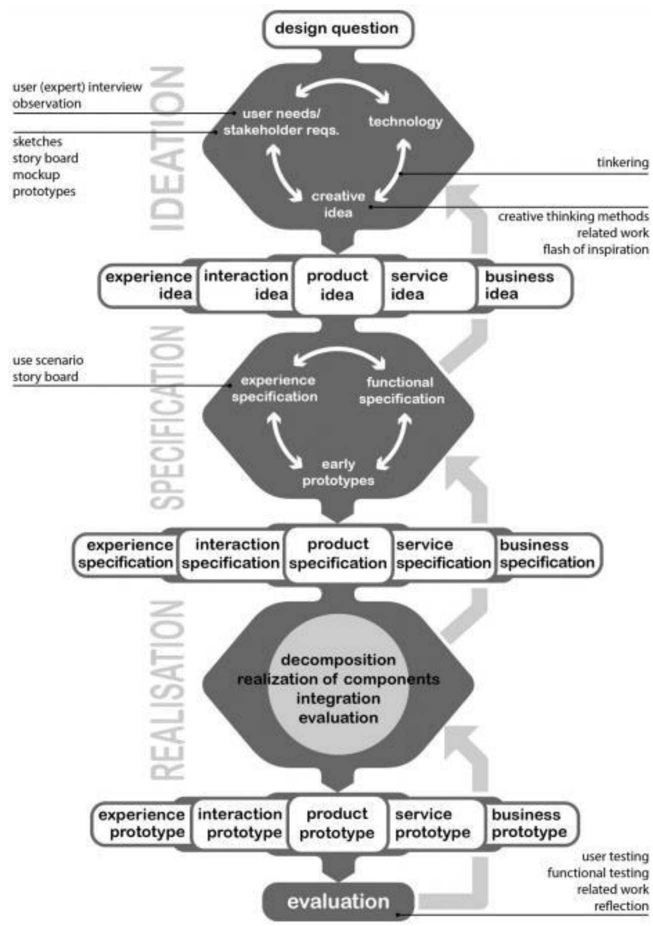


Figure 21: the Creative Technology Design Process.

Corona implications and adaptation

During late 2019, a virus by the name of COVID-19 spread across the world, affecting the Netherlands as well. During time of writing, there is still a full lockdown in place, which means that it has great impact on the testing phase of this project. Because of these events, I am forced to use only my house members as participants, which are a total of four people. This will have influence on the results, because such a low amount of participants will make the results very biased. It is therefore not possible to use statistical analysis on the results because this has little effect with this little amount of people. instead, the tests will focus to be more qualitative instead of quantitative, and the test will be more in-depth.

4. Rowing setup

4.1 Current setup + boot

A more in-depth description of the booting order and all possible errors can be found in the manual that is attached in Appendix A. Currently, the project uses a HTC Vive Head-mounted Display with three HTC Vive trackers, and an RP3 model T. The ability to run VR is through the popular gaming platform Steam. In order to run the project, a computer with SteamVR needs to be installed, a room setup needs to be done and the trackers booted up in order.

4.2 Vive Trackers

In order to track the movement of the handle, seat and back, previous projects used HTC Vive motion trackers. These are small devices that can accurately be measured and used in the Unity environment. There are three trackers that are attached to the rowing machine, and the 'Head-mounted display', or HMD for short, is also used as a tracker. See figure 22 to the right for exact locations.

Figure 22: the latest setup, with trackers on the machine.

4.3 Lighthouses

The virtual reality setup requires two 'lighthouses', which are small devices that are located high up in the room and serve as a depth-sensor in order to track the locations of the headset and trackers. When setting up these devices it is important to keep in mind that all trackers and the headset should be in direct vision with both lighthouses, meaning the devices need to be placed strategically in order to not lose tracking while rowing.

4.4 Recommendations

As of now, the setup process is slow and has a high chance of being incorrect. For one, the trackers need to be booted up in a certain order, and on a certain location. This takes time and effort to get right, especially considering the trackers turn itself off after 10 minutes of being idle. This could potentially get in the way of user testing and accessibility in the future, which is why there should be a better tracking solution. This could be maybe elimination of one or more trackers, and relying more on the headset to calculate distance between trackers.

Another downside of being restricted to only three devices at the same time, is the inaccessibility of the VR menu while using VR. Normally, this can be found by using the normal controllers, which have buttons and functions. But when using only trackers, this is not possible anymore. This makes it hard to step in and out of the VR environment or adjust settings for the user. A possible solution could be the expansion of a maximum amount of devices. Currently, there is one dongle that supports a maximum of two extra devices. It is possible to use another one, which allows Steam to support more devices.

5. Virtual environment

5.1 Previous design

The previous state of the project was a simple unity environment originally made by Koen Vogel. The new design for the boat that is used in the project of Sascha Bergsma is done by this researcher (me). The environment was narrow and cartoon-like, without much distractions. (see figure 23) The user interface for the feedback was all placed on or in front of the boat, which is the direction the user is directly looking.

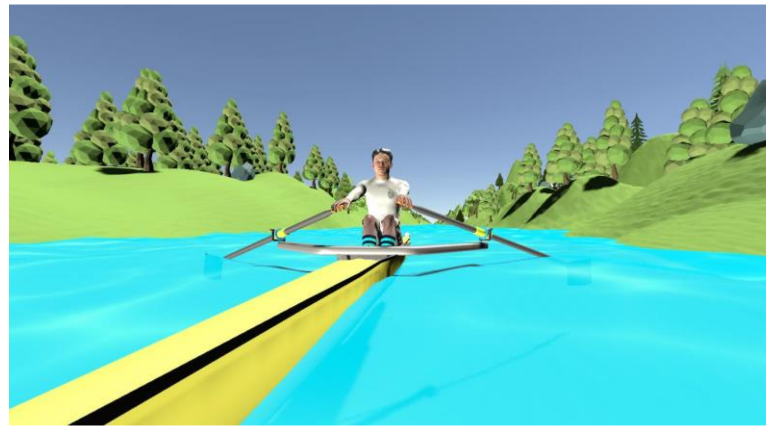


Figure 23: the old environment design.

Another environment mainly used for testing purposes was the 'RP3 room', which featured only a simple room with an RP3 model instead of a rowing boat. This feature also had a slightly different feedback system.

However, there were a few adjustments needed to better fit the game theme of this current project, which is why a few new design choices were made. For example, from personal experience, the water on the river, which had waves, induced motion sickness. This is because rowing on similar real waves is very unstable. Not only this, but the environment itself is also too narrow and unappealing. Lastly, the UI is not very optimal: the large screen in front of the user is very big and blocks the view of the user.

5.2 New design

In the newer design, a completely new terrain was built that adds more realism to the scene. This is done using the Terrain builder asset in Unity. The water was adjusted so it is completely flat and more realistic.

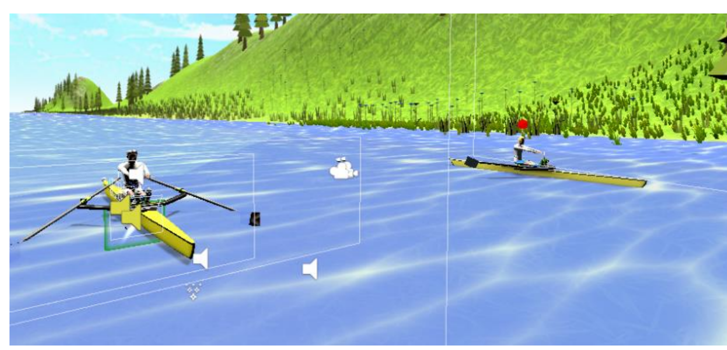


Figure 24: The new design.

The river is more broad, mostly because of the addition of an opponent. This is a similar looking avatar that can be seen by looking to the left. This opponent is not attached to the environment, but close to the position of the user. This is because the user itself is theoretically not moving, but the environment is. Essentially, the opponent is only either moving away from the user, or approaching him.

Lastly, the UI is now used in a different way. Instead of placing feedback in space near the user, now the UI is attached to the camera, similar to other first-person games. This way, the user is always able to see his tempo, speed, distance to the opponent and technique errors, while still being able to look around freely. This enables the user to focus on competing with the bot to their left.

5.3 Recommendations

There are a few parts about the environment that might need improvement in the future. First, the environment is still lacking realism. This can have impact on the immersion of the feeling of rowing, because the lighting and environment is not behaving the same way as in real life. This can be solved by using the High Definition Render Pipeline in Unity, which adds very realistic lighting and camera movements like motion blur. This is hard to simply switch to; in order to get it working, the whole project needs to be re-assembled in a completely new Unity file, which costs a considerable amount of time.

Another part of the virtual reality is the game feeling of the project. At this point, the Unity project is booted up, and the user is immediately thrown in the world without going through a menu, tutorial or time to get ready. A nice improvement would be if for example a ‘start’ and ‘finish’ is added, so the project can be started and terminated by itself. This would also add to the comfort of the user.

The last part that could maybe use improvement is the avatar in the boat, because this figure still experiences bugs. This can be seen by sliding up too much or being too small for the in-game avatar. The physics and joints of the legs sometimes show buggy behavior, which can distract the user. This could be solved by adding restraints to the joints, or maybe using another more simple character.

6. Feedback design

This chapter describes the improvements made on the feedback design, and the user tests. As mentioned before in chapter 3, every kind of design in this project uses a design cycle which consists of an ideation, realization and evaluation phase.

6.1.1 Previous options

In the virtual environment, there were multiple types of feedback created. The three main points of feedback were the handle height, posture and stroke speed.

Handle height

For this feedback, there were multiple designs created in order to perform user tests. The two main types were visual and auditory.

The visual handle height was created by making a drawn trajectory which was visible to the rower. The goal is to move the handle along the trajectory with the intent to learn the rower the correct handle height. If the handle has deviated too far from the correct path, a red trail starts to appear, signaling to the rower that their positioning is off.

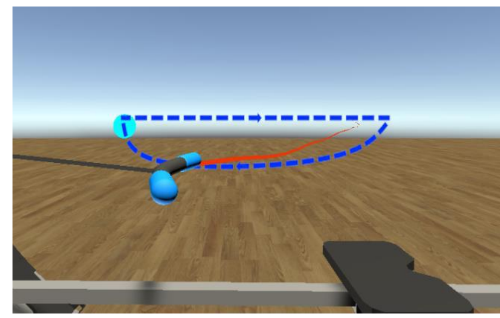


Figure 25: handle trajectory feedback.

This trajectory could either be seen from the right side of the rower, on a display directly in front of the rower, or immersively by putting it directly under the face of the rower. After user testing, the side view was more favorable as this was much more visible to the rower during the exercise.

Another way of correcting the handle height was though sound effects. The handle would have a certain height in space, which would correspond to a pitch, for example: if the handle moved vertically upwards, the sound pitch would get higher as well. The ‘correct’ frequency would be played in the left ear, and the pitch of the real position in the right ear. The goal for the user was to match their pitch on the right side with the correct pitch left. The advantage of such a feedback system is that the user would be able to hear instantly if the handle height would be incorrect.

Velocity

There is a difference in speed depending on which part of the rowing stroke a rower is in. The drive, which is the fast movement of pushing away, is very fast compared to the recovery, which is slowly gliding to the front again. As a rule of thumb, the speed of the recovery is about two times longer than the drive. It is very important that the recovery should be done slowly, so a trail was designed to show the rower whether they are going too fast or too slow. The separate feedback trail looks like the trail in figure 26, but this feedback could be combined with handle height, which then turns into a small blue dot, as seen in figure 25.

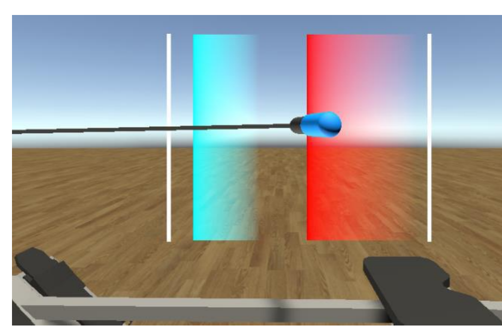
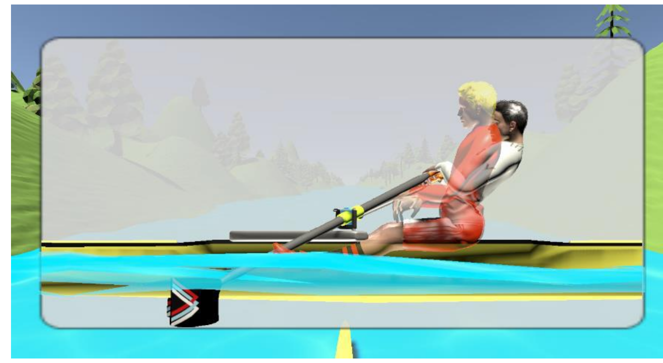


Figure 26: velocity feedback.

An alternative way of giving feedback on velocity was by using haptic feedback. This was done by attaching a small vibrating motor to a glove which the rower needs to wear. In case the rower moves too quickly, the motor on top of the hand starts vibrating. Similarly, if the rower moves too slow, he can feel a vibration this time under his wrist.

From the user test, it became clear that the velocity training was rated to be harder than the handle height training. This seemed to be because the haptic feedback was less intuitive, and the vibrations could potentially disrupt the rowing movement. Additionally, the vibrations could not always be felt, making it hard to correct him/herself.

Posture



For correcting the back movement of the rower, there was only one type of feedback made: a visual that can compare the posture of the rower and a correct example of a well-executed rowing stroke. This stroke is based off of the stroke recorded by Sascha. The feedback makes use of a ghost rower: the red figure that appears when the technique is incorrect. Similar to the handle height feedback mentioned previously, this feedback system also works with deviation: if the rower differs too much from the example, then the ghost rower appears and overlaps the image of the real rower until the rower corrects himself. By showing the ghost briefly, the rower immediately knows if their back angle is rotated too early or late, and they are able to respond immediately by seeing their own posture in front of them.

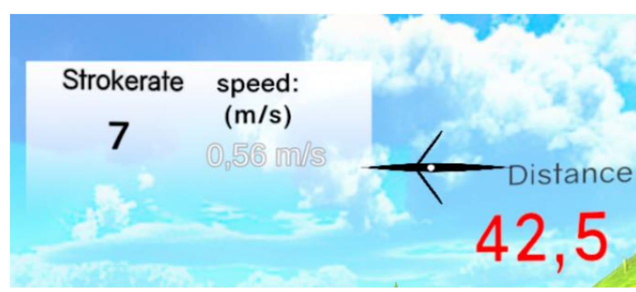
Results from the user test of this feedback system was also quite positive: the users were able to immediately see their errors and correct them. the image is displayed very clearly and was intuitive.

6.1.2 New design

The new design of the feedback is a combination of game elements and positive feedback. The previous feedback system featured multiple ideas of showing the errors of rowers, so to build on this idea, some positive feedback and rewards will also be added. These can be found in the User Interface (UI) and in the environment.

User Interface

Instead of placing feedback on a certain spot in the environment, now real-time data will partly be 'attached' to the vision of the user. This means that the user is able to keep paying attention to the data without having to look at a certain place in the environment. This kind of user interface display is also similar to other first-person video games, and could be recognized and be intuitive for users to understand.



From the survey, respondents have indicated that the data they pay most attention to is speed, distance, stroke rate, and wattage. These elements seem most relevant for rowers, so in order to still provide the rower with this information, it will be displayed above their vision at all times. Currently it is still not possible to make use of the real data coming from the rowing machine, so instead only the stroke rate and the speed (in meters per second) will be displayed. The speed is also an indicator for the performance of the rower: if the rower does not row hard enough, the text turns red. Similarly, if the rower puts in enough effort, the text becomes green.

The distance to the opponent is also displayed. This is done for multiple reasons: First, the user should be able to keep track of their distance compared to their opponent without needing to turn their head to the left. This could help users focus on their own technique and reduce the time of looking in a different direction, while still being competitive. Second, the text that displays the distance also functions as an indicator, similar to the speed: if the rower makes a mistake in either handle height or posture, the user is 'slowed down' by increasing the distance between the rower and the opponent, and the text will appear red. On the other hand, if the user consistently rows well, a reward in the form of a 'boost' is given: the distance of the user and opponent is decreased and the text appears green briefly. By giving this text an according color, the user is able to only glance briefly to this part of data and understand how well they are performing.

Another feature that was added is the 'boost' feature, as seen in figure 27. This can be seen on-screen at all times, and features three grey circles with increasing diameter. If the rower is able to make a rowing stroke without making a single mistake in either posture or handle height, a circle will appear green. If this is done consecutively three times, the boost circles reset to grey, the screen starts displaying a green vignette around the edges, and the speed of the rower is temporarily increased. By introducing such a feature, the rower will be rewarded for consistency in their technique.

Figure 27: the boost function on the user interface.

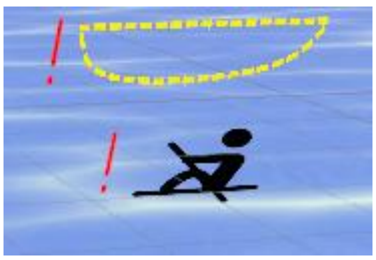


Figure 28: Icons that may appear during a mistake.

Furthermore, on the user interface errors in technique are also shown. When the rower makes a mistake, then the logo according to the type of mistake are shown. These are 'dashboard notifications', meaning they appear in front of the user whenever a mistake is made. This can help the rower see what kind of mistake they are making, and focus on that type of feedback accordingly. The two logos that are used for handle height and posture are shown in figure 28.

<u>Environment</u>

Around the rower itself is feedback present. This can be found mostly around the opponent, but also in different locations around the rower.

The opponent is added to motivate the rower in the form of competition. From the literature review in chapter 2, this game element seems to have great effect on the motivation of athletes if the competition is close. That is why some features and rules around the opponent were added:

- The maximum distance between the rower and the opponent is 20 meters.
- The speed of the opponent is slightly faster than the normal tempo of the rower.
- If the rower makes a mistake, the opponent's speed will immediately increase.
- If the rower is putting in more effort into speed and reaches a certain speed, he will briefly have a slightly faster speed than the opponent.
- The boost will gain the rower more distance than the opponent gains in the case of a mistake.

By implementing these rules, the rower can only catch up if he puts in effort in both technique and speed. Alternatively, the rower is also able to see the consequence of their mistakes: if their technique is incorrect, it is not possible to win from the opponent. This 'forces' the rower to learn good technique in a way and could be helpful for learning a repetitive movement like rowing.

Other environmental feedback can be seen in front of the boat, in the direction the rower is looking. To add more meaning to the speed feedback, a particle system is attached to the boat which only plays when the rower's speed reaches a certain threshold (see figure 29). The size of the particle system or the amount of particles is determined by the power input of the rower: if the rower rows hard enough, the speed stays longer above the threshold and produces more particles. The particles are an indication for the rowers to assess how fast they are rowing, but could also act as a motivator: in order to produce more 'fireworks', the rower has to row harder.

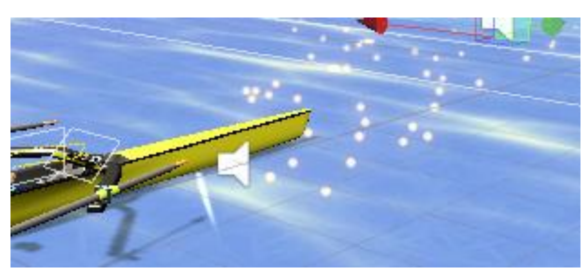


Figure 29: particle system that appears with a certain speed.

Sound

The last kind of feedback that was added was sound effects. In total, there were three sounds that provided feedback to the rower about posture, handle height and speed. All sounds are related to the type of feedback the user is receiving.

Whenever the rower makes a mistake with their posture, an 'ouch' sound is heard, to insinuate a back pain. This sound also features in the popular game *Minecraft*[4]. When the handle height is incorrect, a loud splash sound is heard. The idea behind this is to let the user know that their blades are hitting the water. Lastly, when the speed is above a certain value, a sound starts playing that resembles the sound of a small creek flowing. This is supposed to sound like water flowing underneath a real rowing boat.

These sounds are carefully picked because of the meaningful information a rower could get out of it. If a mistake is made, the sound is played as soon as the notification shows on the user interface, meaning the user will hopefully be able to link the sound feedback to the type of mistake they are making.

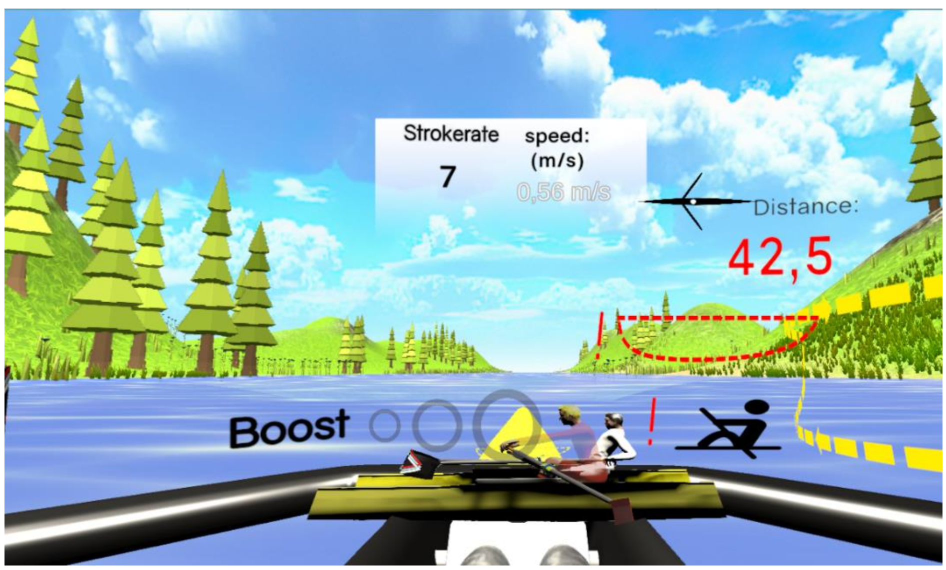


Figure 30: image when all feedback is working at the same time.

[4] https://www.minecraft.net/nl-nl/

6.2 User Testing

To test how beginning rowers react to these different types of feedback and game elements, a user test was conducted with four other house residents. These points were evaluated by interviewing the participants, a survey afterwards, and video or screen recordings of the whole session.

Of these four participants, two had prior experience with rowing. One of them has rowed for a long period of time, while the other only rowed in a rowing boat once. All of the participants have used virtual reality goggles before.

The goal of the user test is to find out how beginning rowers react to the different types of feedback and whether they have effect on the performance and motivation of the rower. The focus is on whether it is engaging, understandable and if the difficulty is doable for a novice rower. The goal is also to look at the competition element and whether this helps the rower improve their skills and put in more effort.

Because there are only few participants and there are a lot of elements that need to be tested, the test will consist of three parts, in which the technique feedback only, speed feedback only or a combination will be tested. This means that the knowledge of results (speed feedback) and the knowledge of performance (technique feedback) will be tested separately, and together once to see how the participants react differently towards these types of feedback.

6.2.1 User test

The user test started by asking the participants to row on the rowing machine without virtual reality for two minutes, to get used to the feeling of the machine. A dynamic machine works slightly different compared to other rowing machines, so this seems an important step in order to keep focus during the actual experiment.

After the short warm-up period, the participants could now row on the machine with VR goggles and the glove, only the environment and UI are completely empty. This is done for two reasons: First, this is a good moment in the test where the participant can adjust the headset to their preference, because the actual test has not started yet. Second, the participant is able to get used to the environment before receiving a lot of feedback at the same time. This could also be advantageous to the test, because the user can hopefully focus more on the feedback during the test without looking too much at the environment.

After the initial rowing phase, the participants were asked to stand up and watch an instructional video at the computer. The video used was the showcasing video of the previous project[5] and while watching it, participants were told that those kinds of feedback (posture, handle height) were also implemented in the test they were about to do.

There are three environments in the testing phase and there are four participants. The environments are:

- Technique only (T)
- Speed only (S)
- Technique and speed (TS)

To avoid bias when selecting a certain order of testing, the participants randomly selected a card with a number, corresponding to the order of testing. The possible combinations can be seen in table 3 below.

	Round 1	Round 2	Round 3
Participant 1	T	S	TS
Participant 2	S	T	TS
Participant 3	TS	S	T
Participant 4	T	TS	S

[5] https://www.youtube.com/watch?v=kD93bxN2cQ4&ab_channel=SaschaBergsma

Table 3: the order of testing for each participant.

After selecting a card, the participants is asked to get ready on the ergometer, and the environment is loaded. In the case of only one kind of feedback, all other parts of the UI are invisible and the disabled feedback type also does not have any influence on the opponent anymore.

The participants are asked to row for about three minutes and to keep their tempo or stroke rate around 20. There are no further instructions but they are able to mention anything they see. To keep the difficulty for every rower the same, the drag factor was adjusted appropriately for each rower on the rowing machine. This has impact on the effort it takes to row, and as a result also the strokes per minute. A participant who is very fit and male will have a drag factor of around seven, while a small female participant will get a drag factor of approximately two or three.

After each session of about three minutes, the headset is removed and the participants is asked a set of questions. These are:

- What did you see?
- What did you pay most attention to?
- What kind of feedback did you get?
- How did you interpret the opponent?
- Is there anything that annoys you while rowing?
- What did you think of the difficulty of the challenge?

After the last session, an additional question is asked:

- Which of the three sessions did you enjoy the most?

Finally, after completing these steps, a small survey that asks about enjoyment is asked. These are similar questions from the survey from chapter 2, but questions are adapted to fit ‘virtual reality’ in the sentences.

6.2.2 Observations

Pre-test

During the start of the test, the participants were getting used to the rowing machine before using the virtual reality headmount. All participants seemed to be hesitant to use the machine in the first few minutes. This could be seen from the lack of power exertion, a delay at the catch and only little sound was coming from the rowing machine. However, after putting on the virtual reality headmount and experiencing the rowing environment, all participants stopped showing hesitation while rowing.

Competition

All rowers had noticed the opponent left to them and also correctly assumed that the challenge for them was to be faster than it. All participants also seemed to generally be focused on this as well, but this differed a bit per person. First of all, it was clear that at the beginning of the test or during the first technique session, most participants were heavily focused on technique, especially when a lot of errors were made. They reported this after the first session and from the screen recording, it was visible that their vision was mostly focused on either posture feedback or handle feedback.

However, after a while the participants were looking more to the left or at the distance indicator on the UI. Especially two participants who have more rowing experience were very often looking over their shoulder and reported that they were trying to stay in front of the opponent. The other two participants were shifting focus often: if an error was made, their focus was completely on their technique and if that was going well, their focus shifted back to their competitor.

The distance indicator was often reported to be a big focus point of the participants, especially when a mistake or boost happened. Almost all participants had said that they were looking at the distance or mostly the color of the distance during the rowing session. Two of them pointed out that the color feedback was very helpful to see whether they were performing well.

One of the participants had made a lot of errors in the beginning of their technique session, which caused the opponent to have a head start. The participant then reported that they were put off by the distance between him and the opponent and his motivation dropped, because he was not able to see the opponent in the corner of his eye anymore.

Performance

This environment was mentioned as most 'relaxed', because of a lack of information on the user interface and around the rower. The focus of the participants was mostly on the stroke rate and the competitor by looking at the distance indicator on the user interface or looking to the left. It was also noteworthy that none of the participants could actively recall the particle system, but did seem to react to it during the rowing session. At first, most participants did not even understand when the particle system worked. After instruction of rowing on higher tempo, pushing harder every stroke or rowing a very slow tempo, all participants understood how the particle system worked and also saw that their speed increased when their tempo or force increased. After discovering this, most participants paid more attention to their opponent by looking at it and sometimes increased their stroke rate.

Participants did mention that there was little feedback, which was slightly annoying to them. Those who had experienced technique feedback in a previous session mentioned that they wanted to see more feedback on their posture. One participant also mentioned that they had trouble making good rowing strokes without the feedback. This was visible with every participant: without technique feedback, their technique was looked significantly worse. This could be seen from the order of using the arms and back during the recovery, and using too much of their back during the drive.

The sound effect which featured a 'flowing creek' sound was unfortunately not very effective: it was not audible above the sound of the RP3. Moreover, it was not possible to play two sounds at the same time, so when an error occurred, the creek sound effect abruptly stopped playing. This is due to the built-in sound effects in Unity, which do not usually support two sound effects at the same time.

Overall the participants found this round the least challenging of the three. In all four cases, they were able to stay in front of the opponent. This was mentioned too: The effort needed to stay in front was lower than other situations. Additionally, if the rower is able to keep a steady pace on the rowing machine, there may be a lack of feedback.

<u>Technique</u>

The observations of this round differed significantly with every participant. In general, feedback on posture and handle height were quite clear, possibly due to the instructional video shown at the beginning of the test. Of course, around these two types of feedback there were several indicators placed in the user interface. These are the pop-up icons, the boost, the indication of speed and sound effects.

First, the icons in the UI were quite clear: almost all participants were able to tell what they represented. The participants also appeared to react to these icons during the test: if for example a handle height icon appeared, they were able to figure out fast that their handle trajectory needed more attention, so the focus and camera angle switched to their hands.

The boost was slightly harder to understand to the participants: only two of the four had found out that it only works with the correct execution of technique. These two had also pointed out that they enjoyed the positive feedback coming from the boost, which are the green vignette around the screen and the change in distance between the rower and the opponent. However, it is hard to work with the boost when a user is a complete beginner, for example: one of the participants had never rowed before, so there were a lot of errors in technique even though they received posture and handle height feedback. If there is an error every stroke, it is impossible to build up the boost, or even figure out how it works. Additionally, mistakes are not immediately visible in the boost: if a mistake is made somewhere in the stroke, the boost will reset only after the stroke has finished. This delay could possibly cause confusion about why it does not seem to work, because rowers may not see the link between the boost and their technique. On the other hand, if a user is experienced with the rowing movement, it takes the challenge away of working on technique. Another participant is an experienced rower, and mentioned that there was a lack of (positive) feedback if no error is made, which could make it less engaging. A remark from another participant was the expectation that the boost would last. It seemed confusing that the boost re-setted after performing three strokes without error, instead of holding on to the boost until a mistake is made.

However, almost all participants pointed out that there is too much information shown at the same time. More specifically, the different locations of feedback on the UI and in the environment were confusing at times. Two participants mentioned that they needed to shift their eyes across the screen very often, which was slightly tiring and distracting, especially when there are multiple things happening on-screen. What also made it hard to keep track of all feedback was the fact that the UI moves all the time, which makes the resolution very low and therefore hard to read. One participant mentioned that they would prefer one ‘dashboard’ with all statistics in a static location in front of them, rather than information attached to their camera.

Lastly, the sound that was added had a mixed effect. The ‘splash’ sound seemed to work adequately, because it played at exactly the same time as when a pop-up notification appeared and participants were able to tell that the sound meant incorrect handle height. The posture sound effect however had less effect. For most participants, the sound seemed simply an indication that something was wrong, but they were not able to detect what exactly about their rowing was incorrect. One participant who has a lot of experience in *Minecraft* reported that they were very confused about the sound and was also not able to correct their back movement during the test. It seemed there was confusion because of the timing of the sound: the splash sound was on point with the dashboard error notification, but this sound had a delay after a mistake was made due to Unity. This could have contributed to their confusion.

Combination

From asking the last question of the interview, this session was most enjoyed by all participants. They mentioned that they felt this session was the most challenging and most engaging. One participant said that he saw the most feedback and could improve best in this session. Another person thought that the opponent was himself from a previous session, and therefore felt more challenged.

Even though all participants favored this combination, none of them could tell exactly why. They were not able to dissect that the three phases were based on either speed or technique.

Enjoyment

All participants have expressed their enjoyment and enthusiasm towards the rowing experience with VR. Some were surprised by how functional it is, or how real it feels compared to real rowing. All participants also filled out a survey with questions about enjoyment from rowing with VR. These results can be seen in figure 31. Because there were only four participants, it is hard to draw a good conclusion out of these results. These participants are also do not completely fit the target audience as they are not rowers, nor have they filled in the previous survey.

There is one participant who filled in all questions quite negatively than the other three, especially the sixth question: "I often give it all I have in a VR ergometer activity", which has the most diverse response. This participant also did not seem to enjoy testing very much, as he often reached out to his phone in between the test settings. Also the question: "I think a VR ergometer activity is very interesting" is answered quite positive compared to the normal ergometer activity.

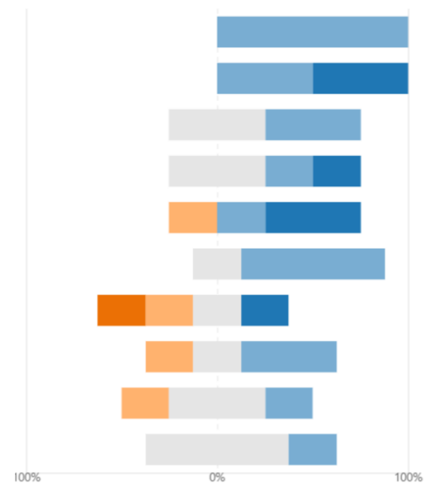


Figure 31: results from the short enjoyment questionnaire.

Other remarks

It is notable that every participant enjoyed the rowing session, and was surprised by the realism and functional feedback of the environment, though there were some remarks about the usage of VR with training:

- The headset was not very practical in the case of training often, because it is uncomfortable to wear it when the rower starts sweating.
- One participant felt slight discomfort when ending a rowing session, because they felt disoriented and did not feel where they were in the 'real' world.
- One participant mentioned some limitations towards technique using VR, and felt that there was not enough feedback in order to learn from it, especially in the long term. This person would heavily prefer real coaching compared to VR.
- The realism of the environment and the avatar was not always very comfortable. One participant said that they were annoyed by how the hands and legs looked throughout the stroke.

6.2.3 Conclusion

It is not possible to draw a good conclusion out of the user tests because of the small amount of participants, but it can give a general idea of the implemented feedback. From all four tests, these points came forward:

- Competition seemed to have an impact on the motivation of the rowers. Often, they looked towards their competitor or mentioned that they often looked at their distance to the opponent. The amount of focus on competition depended on their technical performance: if there were errors in technique, the focus shifted to technique feedback. If this was resolved, the rower paid attention to the opponent again. The participants who had more rowing experience generally paid more attention to their competitor.
- The technical feedback had mixed results: the posture and handle height were clear, but the notifications not immediately. The boost was not very intuitive, but after discovering how it worked, was still rewarding. The technique feedback also helped the rowers to learn the rowing motion reasonably.
- The speed feedback was quite clear, but there was not a lot of feedback or difficulty. The rowers liked the color feedback in the speed. After a while the particles were clear too, and may have acted as an indication for desired speed. Though without the technique feedback, the performance of the rowing motion got worse.
- The sound feedback has potential, but in this case it was not very effective. The splash sound was clear to most participants, but the ‘ouch’ sound was confusing at times. This could be due to a delay in sound, possibly making it hard for rowers to understand what the sound is for.
- The combination of speed feedback and technique feedback was the most favorite session for every participant.
- The user interface is generally quite intuitive, but there might be too much information on the screen. This causes the user to move their eyes a lot on the screen and be distracted easily from their focus. Additionally, the data is harder to read when the user is moving their head, which can be slightly discomforting.
- Participants seemed to generally enjoy the activity, and have expressed this. From the survey it is not possible to draw a good conclusion, but there is a lot of interest.
- There were some remarks that there is a realistic feeling of rowing while rowing with VR. However, there are some parts that need more attention to realism as it might provoke an ‘uncanny valley’ feeling.

7. Discussion

In this chapter, findings from this research will be presented and compared with related work. Afterwards, limitations during this project will be discussed, and a small ethical risk sweep analysis will be highlighted.

7.1 Findings

First, the findings of the whole research will be highlighted again and discussed.

Survey

From the survey, a few interesting points came forward about the enjoyment, engagement and experience of the rowing machine, as well as information about the opinion on the RP3.

Enjoyment

First of all, the enjoyment for a rower seemed to be significantly less when rowing on an ergometer compared to a real rowing boat. This is also a result that was expected from personal experience and the apparent absence of feedback from the rowing machine. However, all rowers were still quite positive in general towards the rowing machine. From the open questions, it was possible to deduce that what rowers like about on-water rowing is mostly the coordination together with teammates, the environment, and moving the boat through the water. But these rowers use the ergometer not only as a replacement, but also as a means of building endurance and competing with themselves. Therefore, the statistics on the screen are still somewhat engaging, and this is seen in the responses as well: rowers mention that they are satisfied when they have reached a better score.

Difference between machine and boat

Even though a lot of rowers use the rowing machine as an alternative for rowing, the machine does seem to be experienced very differently compared to real rowing. This result was anticipated, but mostly out of personal experience. Respondents mention that the ergometer is mostly beneficial for learning technique without a lot of factors, but also answered that learning something new on the rowing is very hard to apply in the rowing boat. These questions were filled out very negatively and maybe almost suggest that ergometer rowing is a different sport altogether. it is probably because the rowing machine is the best current alternative to rowing, but it does seem like the rowing machine is very limited in helping a rower to improve.

Data about performance and technique

Of all available data that can be found on the screen of a rowing machine, almost none give any feedback on the technique, performance or improvement of the rower. This is visible, but after sending out the survey it is now visible as well that the rowing machine lacks feedback, mostly about technique. This is something the rowers would like to see more, especially about subtle elements from the stroke like balancing and the catch. The survey also indicated a significance in difference between the two datasets. However, this was not completely reliable, because the two datasets had different reliabilities which were not very high values.

Concept 2 versus RP3

Almost all participants are used to a Concept 2 and most have done a lot of training on that machine. However, about a third commented that they would still prefer the RP3 over the Concept 2. The questions regarding the realism and preference per scenario were all answered in favor to the RP3: there was a positive reaction towards RP3 in terms of realism and learning technique. From these answers, it is apparent that a dynamic rowing machine might function better as a ‘rowing alternative’: it seems to feel more similar to a real boat, and a lot of participants prefer to train on an RP3 for learning technique over a Concept 2. This may indicate that there is a growing group of rowers who want to use dynamic machines and that the RP3 is a good machine to close the difference in experience between the rowing boat and an ergometer.

User test

Competition

In the literature review, a few articles were reviewed that covered rowing with opponents and whether this has influence on the performance of the rower. Rowing against an opponent really did seem to help the participants to motivate. There were participants who mentioned how they wanted to win from their opponent, while others were often looking at the distance towards the opponent. In any case, this outcome did support concerning literature. [22, 26, 32]

However, one participant had mentioned how their motivation lacked when the opponent was too far ahead and when he was not able to see it anymore without turning his head over his shoulder. This is a similar result found in literature [26, 28], and highlighted in the literature review. For the participant, the limit was the point of turning his head over his shoulder in order to see the opponent.

Feedback

There were some parts of the feedback concerning technique that did seem to work, and some that worked less. First of all, the boost was not always as clear. For some participants it took some time before they had figured out how it worked, but for some this never happened. This can be due to different levels of rowing experience: one participant who had rowed often before had no trouble figuring out how the boost worked, while another who did not know how the rowing stroke worked did not have a chance to focus on the boost. There were a lot of differences in efficiency of rowing, so the results varied a lot. In the case of a total beginner, the feedback might have been overwhelming or too hard to grasp. It seemed that if the rower was performing the stroke correctly and rowing at a steady tempo there was not enough feedback anymore, but if the rower was performing badly, there was too much information at the same time. However, the feedback did seem to be engaging, because participants had most focus on their technique combined with competition. The boost was mentioned as rewarding according to the people who understood, and the indicator of the opponent as well as the sound and notifications did seem to provoke a reaction with the participants.

The performance or speed feedback also had effect on the rowers after they understood how it worked. The participants mentioned that the color change in the speed text and distance text was very helpful and gave a good idea of whether they were performing correctly. The particle system also did seem like it created a reaction, because the rowers had tried to speed up in order to trigger the particles. However, this was not actively remembered when asked about it afterwards.

The design user interface itself was based off of a normal user interface similar to games, but when using virtual reality goggles, this design does not work very properly anymore. This can very well be because the shape of the screen for the participant is not squared but round and the edges are unfocused. Moreover, if the participant moves its head, the resolution seems to low to be able to move the UI smoothly too. It seemed that for VR, a different type of user interface is needed than one that is used on normal computer screens.

Enjoyment

Of the three tested combinations, the one with a combination of feedback and technique was most enjoyed. This was probably due to the difficulty of the challenge: the participants needed to perform well with technique and force. In this session, it also had more effect if both went well: if the speed and technique is correct, this would add to the speed and vice versa.

With the amount of participants, it is hard to draw a conclusion out of the user tests. From the small survey, there was no visible difference between this survey and the first questionnaire about enjoyment on a rowing machine. However, all participants did mention that they had definitely enjoyed the experience and would like to see and help more.

Motor learning

This project has focused on helping beginning rowers learn technique by showing the rowers in real-time their mistakes in front of them. This could be an effective way for a rower to correct himself, but only this ability to correct will most likely only last shortly after the feedback. The next step is to create an idea that makes rowers remember in their muscle memory how a movement works without needing any feedback. This project has made steps in this direction by introducing competition: The rower suddenly not only sees his errors, but also his consequences. In order to win, the rower is therefore 'forced' to row as correctly as possible. This could mean that there is a chance that the rower will more actively learn the rowing movement with the help of technique feedback.

7.2 Limitations

<u>User testing</u>

Because of the situation involving COVID-19 at the moment of testing, it was not ethical and therefore not possible to ask any other participants other than house residents. Only four people was definitely not enough to fully test every aspect of the rowing setup, so in order to still get meaningful results, the test was a little more extensive than intended. It was however also not possible to use any statistics or draw real conclusions out of the results, but they do provide meaningful information.

<u>Possibilities with current setup</u>

Even though the rowing machine, headset and trackers are able to calculate aspects of the rowing motion like back angle and handle height or speed, it is still quite limited. There are parts of the rowing stroke that the current setup is unable to detect. Examples are: relaxation in the back, pulling too early with the arms, or inadequate usage of force. Therefore, the setup is able to teach beginning rowers the principles of rowing well, but for more advanced feedback it is still not completely feasible to rely on such a setup.

<u>Complexity of the Unity project</u>

This project is in its third usage cycle, and a lot of features have been added or removed. Because of this, there is not a very clear structure in terms of scripting, referencing and usage of feedback in other ideas. It is also difficult to understand the project well, because there are a lot of hidden settings that are not optimized into for example a single button, which means the project user needs to activate and deactivate separate game objects in the scene. For long-term usage of this project, this is not a very sustainable manner of creating a project, especially when there is a desire to use certain components of the feedback into a new project. Because it is almost impossible to trace back all settings and game objects, it takes a severely longer time to understand and rework the project.

<u>Feasibility of using a virtual reality rowing setup</u>

Virtual reality headmounts are advantageous when there is a desire to create an experience that is similar to rowing, and an RP3 is an effective rowing machine that contributes to this experience, but the setup itself is not very optimal for normal usage. First of all, the whole setup costs a big amount of money that is probably beyond the budget for users that simply want to learn how to row. Secondly, the usage of such a VR system has its disadvantages when it comes to comfort for the user. When the rower starts perspiring, this can get into the VR set or the glove, which is not very hygienic. This can be potentially solved by attaching the hand tracker to the handle and for example using VR masks.

Nevertheless, such a setup is still quite feasible in the case of rowing at home. It does not take up more space than the rowing machine itself and the trackers can be attached to a normal rowing machine as well because it essentially works the same.

7.3 Ethical risk sweep analysis

First, it is important to try to state and understand potential moral risks that may arise from this project. The question that will be answered is: "Which design choices could possibly harm people or other stakeholders, or are likely to spark acute moral controversy for others?"

Virtual motion sickness

A virtual reality headset lets the user perceive a different world. Because the headset is covering the eyes, the user is completely visually immersed. Sometimes, this can cause motion sickness. For example: if the user is in a VR environment in which they are falling, this may feel physically real as well, even though in reality, they are standing still. This could cause the brain to lose balance, and as a result, the user might feel sick, similar to 'normal' motion sickness.

Insensitive to outside environment

When the user is wearing a headset, it is not possible for him to see surroundings anymore. It is possible that the user can accidentally harm objects, other people or himself because of this loss of sense. With VR, it is also possible to audibly immerse, which means the user is also not able to hear the outside world. In the case another person were to grab the user without warning, the reaction of the user could lead to harm himself, the other person or the environment. In any case, the loss of these senses to the 'normal' world could lead to harm or damage. However, the user in this case will be sitting down and fixed to a rowing machine, which is located on a certain place on the floor, which means it could possibly reduce the chance of injury.

Privacy

While the user is wearing a headset, it is not possible for him to see other people in the same room. This allows the situation of having bystanders without the participant noticing, which may lead to situations like bystanders staring at the user without consent. Furthermore, the participant in the test gives data about their age, gender, weight, experience and length, which is sensitive data. If this data would leak out, this could mean a breach of privacy for the participants.

Injury

It is possible to hurt oneself while using VR. The damage could be more significant, because it is not possible to see the floor or surroundings, so the user is not able to see where or on what they are falling or colliding with. In the case of the rowing situation, injuries could be:

- Rowing injuries stemming from bad technique or posture;
- Falling off the rowing machine, however this chance is small because the user is strapped on at their feet;
- Losing balance while standing up or sitting down on the rowing machine as a result of disorientation (because of the headset);
- Hitting the walls or the rowing machine.

COVID

Currently, the Corona virus is very active in the Netherlands because of many incidents per capita. The participants of the test, but also all people using it could possibly contract the virus via either the rowing machine or the VR headset. On the rowing machine, the most touched places are the handles (which are held with the hands), the seat, the shoes, the flywheel and the rail underneath. The VR headset also has a sponge-like material where the face of the user presses against. If one of the users or participants happens to host the virus, this could easily be transmitted through the (padding of) the headset, or the rowing machine.

Perception errors of the participant

The environment in VR is made as realistically as possible to the real rowing experience. The user might get too used to this environment rather than the real rowing environment. This could cause the user to perform very differently afterwards in a real rowing boat, or could lead to injury, capsizing or disappointment. In the case of capsizing, there is another stakeholder that receives damage, which is the rowing association.

Virtual isolation

The user might develop more enjoyment towards the virtual environment than the real rowing experience, which goes against the goal of the setup. It is also possible that the user likes the virtual reality world more than the real world, meaning the user will spend significantly more time in the virtual world. This can possibly lead to self-isolation, which is not the intention of the design.

Ethical pre-mortems and post-mortems

This step in the toolkit is about envisioning situations that can arise or have happened from small ethical problems while using the system. Pre-mortems are forethought situations, and post-mortems are situations that have already happened. This project is currently a prototype, which means post-mortems are not included in this part. The following pre-mortem is created by putting together certain risks from the risk list above.

Injury

A certain person at home wants to try out the VR rowing experience. He has all the equipment: the machine and the VR set. Shortly after beginning, he tries to learn from the feedback given in the game, but still feels back pain after every rowing stroke. Agitated, he stops rowing and feels dizzy because of the odd effects in the software compared to real life. He stands up, but loses balance and begins to fall. Unable to see the floor, he sticks out his hands but falls with full force on his wrists earlier than he anticipated. His wrists and back are now injured and needs to see a doctor.

COVID-19

A certain person has the VR rowing system at home, but really wants to show his friends how amazing it is. Excited, he invites a few of his friends at his home to come try it. He does not know one of his friends actually has a cold and matching symptoms to COVID-19. He passes the headset on to his friends without taking any measures against a potential transmission of the virus. His friend later lets him know he does indeed have the virus. A week later, all of his friends suddenly start developing symptoms.

Expanding the ethical circle

It is very easy to focus on only one group while designing a product, but it is important to include all stakeholders in this project to reduce ethical negligence or harm to certain stakeholders. Here, only the most important and direct stakeholders will be mentioned.

The beginning student rower

this is one of the people the project uses as a target audience. These are people from 18 years and older who join a student rowing association without any prior knowledge to the sport and are willing to learn how to row.

The beginning rower at home

These are people who want to learn rowing at home on their personal ergometer. Compared to the student rower, these people have less connections with experienced rowers and coaches, meaning this person has less insight on their technique or performance. This user could develop injuries more because he does not have the support of an experienced rowing coach to correct him.

Coaches

Though these people will not use the system itself, they might still use it as a tool for their trainees. Therefore, it is important to include them as stakeholder. The system should maybe be made in a way that does not completely replaces a coach, but can be used better as an aid.

Public Gym person

This person likes to exercise at their local gym and wants to row on a rowing machine. Again, this person has less access to experienced coaches. A public gym also might increase chances of contracting the Coronavirus because it is a public space. However, the current design of the rowing experience is not meant to be in a public gym yet, but if that were realized in the future, then the design might need to be edited, because the goals and desires of a gym person might be very different from a beginning (student) rower.

Case-based analysis

Virtual reality is not a new concept anymore, so there have already been different tests, games and situations using VR that we can learn from. By reading into other similar situations, it is not necessary to re-invent the wheel. Instead, a few similar works will be described.

A Tool for Improving Occupational Safety and Health

According to Grabowski (2020, Ch 1), VR can be applied in a lot of situations in order to train people for certain situations. This can be for example a housefire, in order to train firefighters the right courses of action. It is also mentioned that VR works well for developing muscle memory, because “movements performed in a virtual environment are identical to those performed in the real workplace.” In order to achieve results for players, the experience has to be as immersive as possible. For example, the simulation should be as realistic as possible, the consequences of the actions of the player should be realistic and the player should be able to fully train without any risk. If this is achieved, VR can achieve very effective trainings, develop muscle memory and make the training more interesting and attractive. This project is similar, because it is also a training situation where the user is fully immersed as a rower in a boat. What is useful about the source mentioned above is that the amount of immersion plays a role in how effective the training is. What we have learned is that it is important to make the simulation as realistic as possible, so the training is most effective.

Remembering the ethical benefits of creative work

While the focus of the other steps was more about what could potentially go wrong, it is also important to think about the ethical benefits of this project.

Better training experience

From the survey and from personal experience, it is apparent that rowing on a rowing machine is significantly less enjoyable than rowing in a real boat. Especially during cold weather or COVID-19 times, the rowing machine is the only alternative left. Additionally, a rowing machine is not able to give any feedback on technique for the rower. It is therefore important to find a good solution to this problem.

Reduce injuries

The most common injury for rowers is back pain, and this is often due to bad technique [4]. In order to prevent this, rowers should have a good example and they should be rewarded as well. By learning basic technique without the need of a coach, they should be able to prevent back pain from happening.

More rowing experience

The VR system plays a big part in this project, because it is able to immerse the player. This will help the rower mentally prepare to row in a boat, and will give them more 'on-water' rowing experience.

Health

By making the system into a game, the player will feel engaged to row more often. This will lead to a better trend in exercise, which is beneficial for their health. It may cause more people to row more, which leads to a generation of better lifestyle.

Think about the terrible people

It is important to think about people who might potentially meddle with technology. These types of people could be:

- Hackers; it may be possible to steal personal information in order to sell it. Another possibility might be to sabotage a person's results which could disrupt their rowing career.
- Thieves; the equipment necessary for this project is quite expensive. This could attract thieves who might want to earn money by stealing and selling it.
- Reckless users; there might be people who do not handle the equipment accordingly, which can lead to damages to the equipment and/or person.

Closing the loop

It is important to know that reflecting on potential ethical issues is not a task that can be 'finished'. Every time a designer makes a new decision, he needs to rethink about the ethical implications of it. It should be seen as a recurring lesson of what we did in the past, and how we can learn from it. But also keeping future goals in mind: in the case of this project, the biggest goal is to engage people. Ethics should also not be seen as a separate part of the design process that 'needs to be done', but it should be part of the process and influence the design.

It is also important to keep in mind that it is not possible to sketch out every ethical dilemma from this project. It is impossible to know how people truly react to it before the product has been released, so to keep track of the implications of people, a data collection of ethical impact should be collected after the release. In future plans for this project, this should be implemented as well so the designers are able to reflect on their decisions.

8. Conclusion

To help beginning rowers provide feedback on their rowing technique and engage them in the activity, an autonomous virtual reality rowing environment was built which can provide feedback about their rowing performance and potentially motivate them by introducing competition. This system is built upon previous installations [2,8] which were mostly focused on creating an optimal feedback system to correct any errors in the back and handle movements.

from initial observation, the common rowing machine lacks engagement because the rower only receives resulting data from their force and tempo, while it does not provide information about the technique of the rower. The rowing machine is also used as an alternative to on-water rowing, but the experience of an ergometer does not quite resemble real rowing. Additionally, a dynamic machine which is used in this project might be able to potentially decrease this different experience. To assess these hypothetical statements, a survey was created that asks about the overall enjoyment, the experience and information a rower gets from a rowing machine, as well as the experience and opinion on dynamic rowing machines.

From the survey, it was possible to deduce that there is a significant difference in experience with a rowing machine and a real rowing boat. A rowing machine seems less enjoyable, and it is hard to apply a learning goal from a rowing machine on a rowing boat. The machine also gives plenty of result-based data, of which the most popular are speed, distance and stroke rate. However, there is a lack of technique-based data and this is something that rowers would like to see. The dynamic rowing machine is also not very popular at the moment among all respondents, but definitely has potential as it seems to resemble real rowing better.

Next, an environment was created that featured competition, and more feedback about both the technique and performance of the rower. The goal was to create a system where the rower would need to put in effort with technique as well as force in order to win from the competition. The feedback on technique and performance were tested separately as well as combined with four participants.

From the user test it was not possible to draw a clear conclusion because of a lack of participants, but the results suggest that (i) competition seems to have an effect on the performance of the rower. This is observed from recordings and user reports; (ii) the added feedback made the experience more engaging, especially the colors and icons. The boost did not work for everyone; (iii) the user interface was generally understood but might need a different approach; (iv) the most favorable environment according to participants was one with both technique and performance feedback.

9. Recommendations

Throughout the project, there were several ideas, problems or other things that came up, which could have more attention in the future. These are points for improvement, but also things the project can expand on or even look at in the near future.

9.1 Improvements

First of all, the project itself would need a rework. Currently, a lot of scripts and game objects are hidden away or referenced in an unusual way. Moreover, the scripting is not very optimal either: there is too much referencing, and it is unclear which script is attached to which game object.

Second, it would be beneficial to the immersion if the project has more realism. This can be achieved by using better lighting, like a high definition render pipeline. But this would require a full re-set of the project, which means reattaching and relocating every script or object together and remaking materials. A benefit from this would be a better and smoother experience of rowing.

9.2 Expanding

A good addition to this project would be the real data from the rowing machine. Currently, only the speed of the handle is used as an indication of tempo, rhythm and force, but the next step would be to add real data to the Unity environment. This would be beneficial in the future if there is interest in training on the ergometer. There is already a small start in this idea: currently, a client is made which is able to translate the data coming from the rowing machine. What needs to be added still is a command to send the data to the server file, and to send that data to Unity using an TCP/IP connection. The code of the client is given in Appendix D.

Another useful addition would be to create a collider system with the water. Currently, it is possible to drag the blades of the oars through the water, but in reality this is not very realistic. It would add to the realism of the project if for example there was a script that combined with an animation, is able to create this sense.

9.3 Future work

The project has already touched on the learning gap between the rowing boat and the ergometer. The next step for this subject would be to expand this to the rowing boat, where the effect of the virtual reality rowing setup is able to close this gap and make ergometer rowing as similar as possible to real rowing.

A start for this project would be to add more feedback. There are still parts of the rowing technique that have not been touched yet in this project, for example the catch. This is a subtle but important movement at the beginning of the stroke, which requires relaxation and good technique. Currently, there is no feedback for this type of technique, but it would be a great addition to the virtual reality rowing project.

Furthermore, a great development would be to have motion trackers installed in the rowing machine itself. The trackers now are not very ideal because of the limited battery and very specific calibration.

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Appendix A: Manual

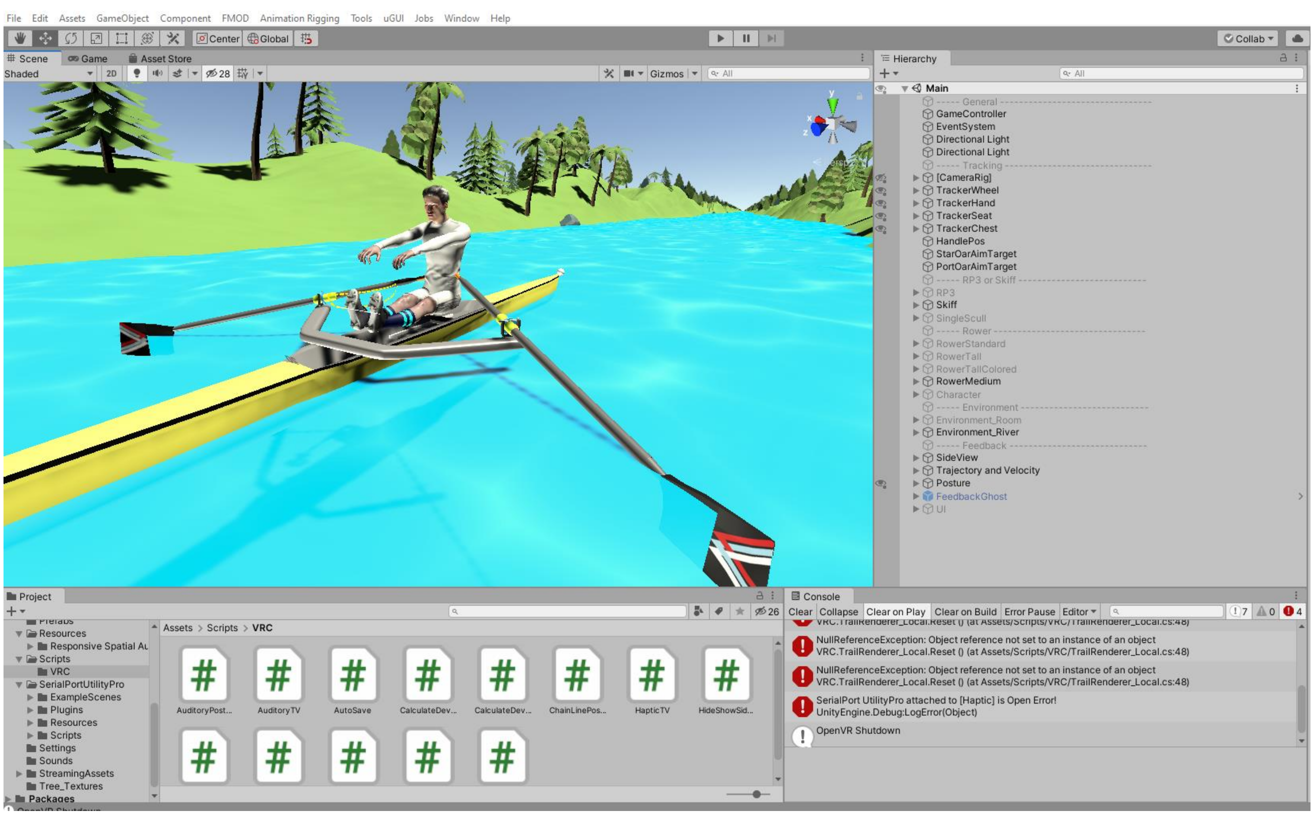
The existing virtual rowing coach is a VR system that consists of a VR headset, 3 motion tracking devices and an ergometer. The system is able to let the user know whether their handle height, back movement and sliding speed is accurate when doing normal rowing strokes.

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.

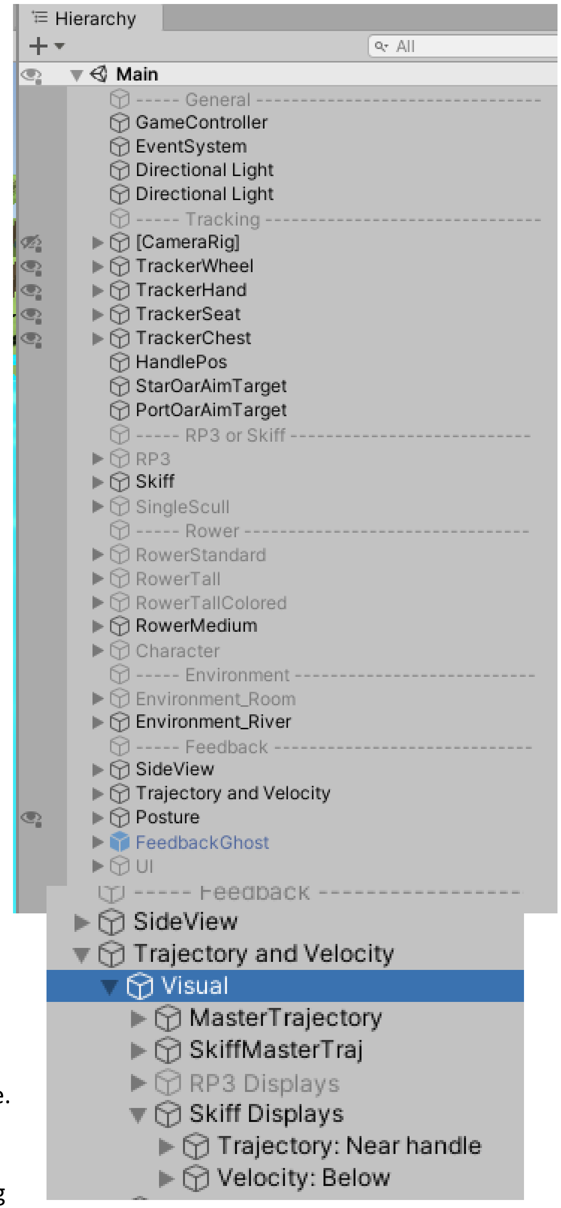
1. **Quick overview**

   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.



In the hierarchy, different game components can be found.
<u>General:</u>
General Unity game components.
<u>Tracking:</u>
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)
<u>RP3 or skiff:</u>
Here there is a choice to display a rowing machine, Empacher skiff or a regular boat-shaped object.
<u>Rower:</u>
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.
<u>Environment:</u>
Choose between a river-like environment or a simple room in VR.
<u>Feedback:</u>
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
    - 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

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: this is the remain of Koen Vogel's rowing project.

UI: old UI of Koen.

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.

<u>Room equipment</u>
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.

<u>Calibration</u>
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
2. the VR hub by clicking ☰
3. Make sure to choose the 'standing only' room setup.
4. The next step is checking if all 'controllers' and the headset are ready. In this step, turn on the trackers in this order:
    i. Flywheel
    ii. Hand
    iii. Seat

To turn on the trackers, press to turn them on, and then press+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. 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.

6. When calibrating the floor, also make sure the headset is facing the flywheel, but then on the ground. Click calibrate.
7. Now to start the software in VR, click play in Unity. This will boot the software on the headset.

<u>Troubleshooting</u>

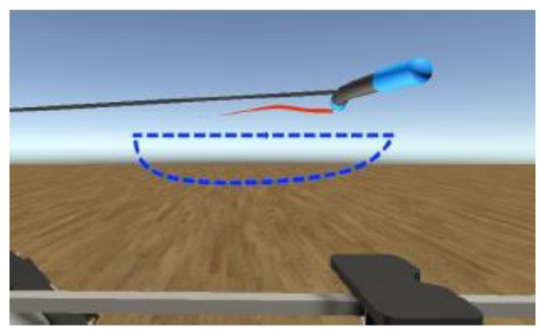
A few errors or mistakes can come up when booting the system. The most common issues:

- 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 leveled 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)

3. Using the feedback system

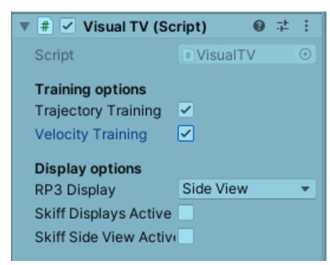
The three most common technique errors for beginning rowers are used in this project. Here there will be a more practical description about each of them.

<u>Target trajectory</u>



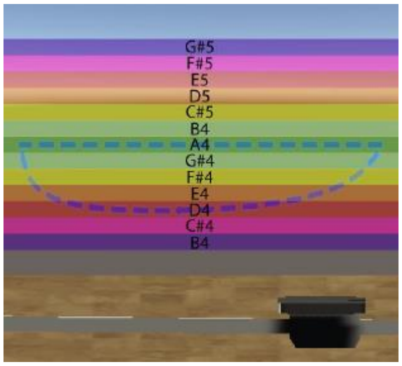
The handle height is one of the factors for feedback. The user is supposed to follow the pattern of the blue trajectory with their handle. The path the user takes can be seen as well because of the red line that is being drawn by the handle. If the user replicates the shape of the trajectory somewhat 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.

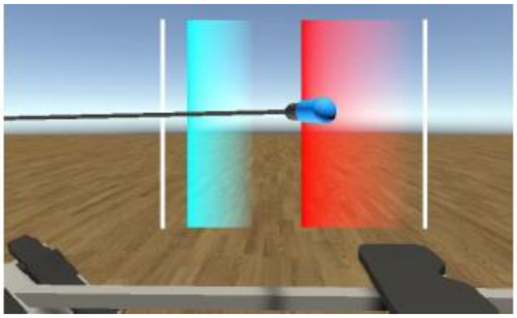
Not only this visual is made, but also the auditory feedback comes into play here. In the left ear, a sound with a pitch can be heard. This pitch is the 'correct' handle height. In the right ear, the handle height of the user can be heard. The different pitches with heights can be seen in the picture 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.

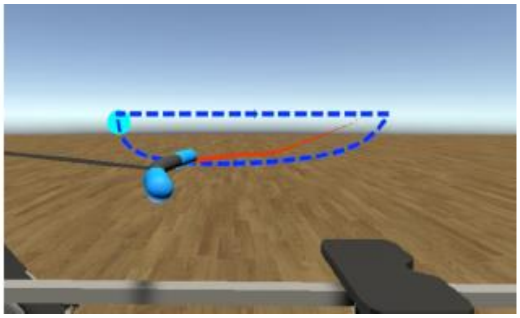


The goal for the user is to match the pitch left with right. Left will differ between an A and a D as seen in the image to the right. Again, if the user performs this task correctly, the sound will disappear and only reappear when he/she does this wrong.

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.

<u>Velocity feedback</u>
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; everytime the user starts a new stroke, the new strokespeed 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 immersively 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 powerbank (make sure it is charged).

<u>Posture</u>

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 to 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 playmode).

Appendix B: survey

This questionnaire is for my graduation project, Virtual Reality Rowing. My goal is to create a VR environment that can help beginning rowers learn proper form and technique and be motivated to reach their goals. To do this, I first need insight in the current experience of rowing on an ergometer. Can you help me by answering the questions about this topic? The survey will take about 15 minutes. Contact information: Annefie Tuinstra; a.w.tuinstra@student.utwente.nl; +316 365 45 351

Intro

- This questionnaire is made for the purpose of my graduation project, which is about 'Virtual Reality Rowing'. Your data will be used to get insights into the experiences of using an indoor rowing machine. This form is anonymous and data will be stored indefinitely on a GDPR-safe server. If wished, personal data can be removed by request. Do you agree your data will be used for my graduation project, as well as potential future research? Y/N

Please highlight which options apply to you.

I am a…

- competitive rower(wedstro)/beginning rower/coach/'comporoeier'/cox/former competitive rower
- Age? (intervals: 18-24; 25-30; 30+)
- Student/phd/staff/working
- Current rowing association (fill in)
- Years of experience (1/2/3/4+)
- Gender (male/female/non-binary/prefer not to disclose/prefer__)

Overall enjoyment of doing an ergometer activity (deze twee kopjes worden afgewisseld)

Considering training using an ergometer: (1-5)

- Doing an ergometer activity makes me feel good.
- I like the physical activity of rowing on an ergometer.
- Doing an ergometer activity makes me feel energetic and alive.
- Doing an ergometer activity cheers me up.
- I think each ergometer training is really interesting.
- Doing an ergometer activity gives me satisfaction.
- I often give it all I have in an ergometer activity.
- I forget the time when I'm doing an ergometer activity.
- I feel relaxed when I'm doing an ergometer activity.
- During an ergometer activity, I feel I can be myself.
- Open vraag: what makes working out on the ergometer fun for you?

Considering rowing in a real boat:

- Doing a rowing boat activity makes me feel good.
- I like the physical activity of rowing in a rowing boat.
- Doing a rowing boat activity makes me feel energetic and alive.
- Doing a rowing boat activity cheers me up.
- I think every rowing boat training is really interesting.
- Doing a rowing boat activity gives me satisfaction.
- I often give it all I have in a rowing boat activity.
- I forget the time when I'm doing a rowing boat activity.
- I feel relaxed when I'm doing a rowing boat activity.
- During a rowing boat activity, I feel I can be myself.

- I consider rowing to be a social activity.
- Rowing helps me connect with my teammates.
- The data displayed on my ergometer screen motivates me to be a better rower.

- Open vraag: what makes rowing on water fun for you?

Learning/training on your preferred ergometer (”disconnect met op boot roeien”) (1-5)
- I learn the same things rowing on an ergometer as rowing in a real boat.
- What I learn on the ergometer is easy to apply in a real rowing boat.
- I think an ergometer is a good replacement for a real boat.
- I can learn how to row by using an ergometer.
- I would rather row on an ergometer than in the boat.
- If I can row well on an ergometer, that means I can also row well in the boat.

- Open vraag: What is the advantage of training in a boat compared to the ergometer?
- What is the advantage of training on an ergometer compared to a boat?

Data feedback (Outcome-related measures) (1-5)**. Here, data on results mean your overall rowing outcome, for example in the form of speed, power and distance.**
- 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.
- During rowing, I compare my data with those of my peers.

- Without a coach, I still know how to improve my results using the ergometer based on the data on my screen.

Performance-related measures (1-5), in the following section when talking about technique this includes timing, posture, or trajectory of the handle by for example looking in the mirror.
- 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.
- During rowing, I compare my technique with those of my peers.

- 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?

C2 V.S. RP3
- How many rowing sessions have you done on an RP3?

(category) beginner – max. 10 trainings, intermediate – max. 50 trainings, experienced – 50+

- How many rowing sessions have you done on a Concept 2?

(category) beginner – max. 10 trainings, intermediate – max. 50 trainings, experienced – 50+

Ergometer preference: (1-5)

- *Which conditions / circumstances make that you opt for ergometer rowing over rowing on water?*
- *Which conditions / circumstances make that you opt for rowing on water over ergometer*

rowing?

- I am used to work out on a concept 2
- I prefer training on a Concept2 for learning technique as opposed to an RP3.
- I prefer training on C2 for trials/tests.
- I prefer training on C2 for races.

- I am used to work out on a Rp3
- I prefer training on an RP3 for learning technique as opposed to a Concept 2.
- I prefer training on RP3 for trials/tests.
- I prefer training on RP3 for races.

- I think rowing on an RP3 feels more like rowing in a real boat than rowing on a C2 does.
- If we went in lockdown again, I would choose to train at home on: (C2/RP3)
- Why? (open question)

- Any last comments? (open question)

Antwoorden van alle vragen:
https://forms.office.com/Pages/DesignPage.aspx?fragment=FormId%3DoUYycvXDxUOs3EOttASsTRNCzmVNGEZBtGheYAd8lPBUQklSVlZOOU9WMlFHRTMwWTVRWUpLWDJQQy4u%26Token%3Dd847cddec6db471e8624f57cdc862b6b

https://forms.office.com/Pages/DesignPage.aspx?fragment=FormId%3DoUYycvXDxUOs3EOttASsTRNCzmVNGEZBtGheYAd8lPBUQlhSRzdHUDJXVkwwRVUyUFlHSlgwTzdTMC4u%26Token%3D3a8f64dc0c9a4764b97a5f7f64f2b8a4

Appendix C: Consent form and information brochure

Ptcpt no.

TOESTEMMINGSVERKLARING (INFORMED CONSENT)

Betreft
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 "Virtual Reality Rowing" as given together with this form.

Main researchers:
Annefie Tuinstra[1], Robby van Delden[1], Dees Postma[1], [1]University of Twente

Contact information
For questions you can contact Annefie Tuinstra (7513HB Enschede, Mina Krusemanstraat 37; +31636545351; s2166321; a.w.tuinstra@student.utwente.nl) or the Ethics Committee of the University of Twente (Drs. Petri de Willigen; UT Building: Zilverling 1051; +31534892085; ethics-comm-ewi@utwente.nl). The Ethics Committee exists of independent exprts from the university and are available for questions and complaints surrounding this research.

Research Virtual Reality Rowing
I hereby declare the following:

- I give consent for my participation during the research period accompanying this graduation project (September – January of 2020) and for the collection and use of anonymous 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 the concerned researchers and will never be made public or used in demonstrations, presentations, promotions or media. All research material will be processed and stored according to the AVG guidelines. All data will be stored for a maximum of 10 years according to the VSNU guideline.

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

☐ I give consent for the publication of anonymous research material collected during my participation in the research.

Date: Place:

Name: Signature participant:

Appendi X **Author**	Dion HoeLian Goh, Razikin, 2015	Schiefelbein, J., Chounta, I., & Bardone, E. (2019)	Murray et al., 2015	Li et al., 2019	Dani Pasic, Danijel Kucak 2018	Kettunen et al., 2017	Parton & Neumann, 2019	Yue Wu, Atreyi Kankanhalli, Ke-Wei Huang, 2015
Title	Is gamification effective?	To Gamify or Not to Gamify?	The effects of the presence of others during a rowing exercise	Gamificatio n-Based VR Rowing Simulation System	Gamificati on in sport – improving motivation for recreational sport	Activity trackers influencing motivation and awareness: Study among fitness centre members	The effects of competitiveness and challenge level on virtual reality rowing performance	Gamification in Fitness Apps: How do Leaderboards influence Exercise?
Small summary	Users used an app that collects their training stats, gives them points everytime they exercise and lets them compete on a leaderboard. This seemed to have a positive effect.	Users of a mobile sports tracking app found the app positively affecting them as they felt they were motivated	Rowing exercise tested for performance : without, with and multiplayer VR. Users performed best with multiplayer VR but did not report to have used more effort.	Users were placed in a VR environment in which they had to compete against bots with random speed, this had worked and could be found in the finishing time and surveys.	Users used an application that tracks performanc e (winning and losing tennis matches) and compares to other users.	Users tracked themselves with watch + polar account to find out if they would exercise more with the watch. Results say that there was no significant increase.	Rowers competed with an on-screen competitor that was slightly faster.	Participants use the Nike runner app and an analysis of their behaviour is done to check whether this app helps them to be motivated.
What motivates /increases performa nce for users?	Leveling system, competition	Tracking progress, competition	Competition , VR	Competition , VR	Competitio n, progression	Track own progress	Competition	Competition, self-tracking
Approach ?	Tracking app	Tracking app	Rowing machine + VR	Rowing machine + VR	Tracking app	App + watch	Rowing machine+VR	Review of tracking apps
Conclusion per article: does it work and how do we know	Yes, through surveys.	Yes, through reports of users	Yes, through HR + distance	Yes, according to stroke, time and HR. More fun measured through survey	Yes, according to survey	No, it had little effect according to user stats. Only a watch may not be enough.	It worked, but not when the competition was too difficult.	Yes, through surveys + statistics

Appendix D: Java client

```
import java.io.DataInputStream;
import java.io.DataOutputStream;

import com.neuronrobotics.*;
import gnu.io.NRSerialPort;

public class OpenSerialConnection {

	private static final String COM_PORT = "COM5";

	public static  void main(String[] args) {


		int baudRate = 9600;

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

		DataInputStream ins = new DataInputStream(serial.getInputStream());

		try{

			//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)

			while(!Thread.interrupted()) {// read all bytes
				if(ins.available()>=2) {
					int firstByte = (int) ins.read() & 0xff;
```

```java
                    firstByte = firstByte << 8;

                    int secondByte = (int) ins.read() & 0xff;

                    int totalValue = (firstByte | secondByte) & 0xffff;

                    float value = totalValue / 750000.0f;
                    //outs.write((byte)b);
                    System.out.println("Float value: " + value);

                    //deze waarde naar de server sturen :)


                }
            Thread.sleep(5);
            }
        }catch(Exception ex){
            ex.printStackTrace();
        }
        serial.disconnect();

    }

}
```

Appendix E: Scripts

```
using System.Collections;
using System.Collections.Generic;
using System.Runtime.Remoting.Messaging;
using TMPro;
using UnityEngine;
using VRC;


/// <summary>
/// This class is responsible for the control of the opponent.
/// this script is attached to the TegenstnaderRower gameobject.
/// </summary>

public class CompPosition : MonoBehaviour
{
   //private VisualTV visual;

   public float moveSpeed = 0.1f;
   private float tegenPos;
   private float zelfPos;
   public float afstand;
   public TextMeshProUGUI afstandDisplay;
   public TextMeshProUGUI tegenstanderDisplay;


   [Header ("References")]
   [SerializeField] private VisualTV visualtv;
   [SerializeField] private StrokeController strokeFile;
   [SerializeField] private ScullBehaviour scullScript;

   public bool techniqueOppFeedback;

   //Update is called once per frame
   void Update()
   {
      //afstand
      transform.Translate((Vector3.forward *-1) * moveSpeed * Time.deltaTime);
      tegenPos = GameObject.Find("TegenstanderRower").transform.position.z;
      zelfPos = GameObject.Find("Skiff").transform.position.z;
      afstand = tegenPos - zelfPos;



      afstand = Mathf.Round(afstand * -10f) / 10f;
      //Debug.Log("Afstand: " + afstand);

      tegenstanderDisplay.text = afstand.ToString();
```

```
        if (visualtv.decel)
        {
            if (techniqueOppFeedback)
            {
                //Debug.Log("Fout");
                moveSpeed = 0.5f;
                afstandDisplay.color = Color.red;
                afstandDisplay.text = afstand.ToString();
            }
        }

        else if (scullScript.realVelocity < 2)
        {
            moveSpeed = 0.3f;
            afstandDisplay.color = Color.red;
        }

        else if (scullScript.realVelocity > 3.5)
        {
            moveSpeed = -0.7f;
            afstandDisplay.color = Color.green;
        }

        else
        {
            // Debug.Log("Goed");
            moveSpeed = 0f;
            afstandDisplay.color = Color.white;
            afstandDisplay.text = afstand.ToString();
            //print(green.ToString());

            if (afstand >= 30 || afstand <= -30)
            {
                moveSpeed = 0;
            }

        }

        if (strokeFile.streak == 4)
        {
            if (techniqueOppFeedback)
            {
                moveSpeed = -0.8f;
                afstandDisplay.color = Color.green;
                afstandDisplay.text = afstand.ToString();
            }
        }
    }
}
```

```
using System.Collections;
using System.Collections.Generic;
using System.Security.Cryptography.X509Certificates;
using TMPro;
using UnityEngine;
using UnityEngine.UI;
using VRC;

public class Vignette : MonoBehaviour
{

    [Header ("References")]
    [SerializeField] private VisualTV visualtv;
    [SerializeField] private StrokeController strokeScript;
    [SerializeField] private VisualPosture postureScript;

    public Image img;
    public float i;
    public float increment = 10f;
    public Image circle1;
    public Image circle2;
    public Image circle3;
    public float a = 0, b = 0, c = 0;

    public Image handMistake;
    public float mistakeColor;
    public Image postureIcon;
    public float postureColor;

    public TextMeshProUGUI exMark;
    public TextMeshProUGUI exMark1;
    public float exColor;
    public float ex1Color;
    public AudioSource postureSound;
    private bool isPlaying = false;


    // Start is called before the first frame update
    void Start()
    {

    }

    // Update is called once per frame
    void Update()
    {

        circle1.color = new Color(1,1,1, a);
        circle2.color = new Color(1,1,1, b);
        circle3.color = new Color(1,1,1, c);
```

```
handMistake.color = new Color(1, 0, 0, mistakeColor);
exMark.color = new Color(1,0,0,exColor);
exMark1.color = new Color(1,0,0,ex1Color);
postureIcon.color = new Color(1,0,0, postureColor);



if (visualtv.decel)
{
   mistakeColor = 1;
   exColor = 1;
}
else
{
   mistakeColor = 0;
   exColor = 0;
}


if (strokeScript.streak == 1)
{
   a = 1;
   b = 0;
   c = 0;
}
else if (strokeScript.streak == 2)
{
   b = 1;

}
else if (strokeScript.streak == 3)
{
   c = 1;
}
else
{
   a = 0;
   b = 0;
   c = 0;
}

img.color = new Color(1,1,1, i);
if (strokeScript.vignetteBool == true)
{
   i += Time.deltaTime * increment;
   Debug.Log("ja doe dan");

}

else
```

```
        {
            i = 0;
        }


        if (postureScript.postureMistake)
        {
            playPostureMistake();
            postureColor = 1;
            ex1Color = 1;
        }
        else
        {
            postureColor = 0;
            ex1Color = 0;
        }

    }

    void playPostureMistake()
    {
        if (!isPlaying)
        {
            postureSound.Play();
            isPlaying = true;
        }
        else
        {
            postureSound.Stop();
            isPlaying = false;
        }


    }
}
```

```
public class ScullBehaviour : MonoBehaviour
{
    #region variables
    #pragma warning disable 649

    [Header("References")]
    [SerializeField] private StrokeController controller;
    [SerializeField] private TransformRecorder handle;
    [SerializeField] private TMPro.TextMeshProUGUI velocityText;
    [SerializeField] private Transform movingPart;

    [Header("Settings")]
    [SerializeField] private Vector3 direction;

    private float HandleSpeed => -controller.moCap.CurrentVelDistWheelHandle.z;
    private static float _currentVelocity = 0;
    [SerializeField] private float accelerationMultiplier;
    [SerializeField] private bool enableQuadraticDrag;
    [SerializeField] private float quadDragExponent;
    [SerializeField] private float quadDragMultiplier;
    [SerializeField] private float linearDrag;
    public float realVelocity;
    public AudioSource creek;
    public LineRenderer speedLine;
    private float lineColor;

    #pragma warning restore 649
    #endregion


    // Update is called once per frame
    private void FixedUpdate()
    {

        //move boat
        movingPart.Translate((Time.fixedDeltaTime * _currentVelocity) * direction);

        //apply acceleration from handle
        if (HandleSpeed < 0)
        {
            float acceleration = HandleSpeed * accelerationMultiplier;
            _currentVelocity += acceleration;
        }

        //apply drag
        var quadDrag = quadDragMultiplier * Mathf.Pow(_currentVelocity, quadDragExponent);
        if (enableQuadraticDrag)
            _currentVelocity += quadDrag;
        else
            _currentVelocity *= linearDrag;
```

```
    }

    private void LateUpdate()
    {
        //display velocity to text
        realVelocity = Mathf.Abs(_currentVelocity);
        //turn on when technique is used
        velocityText.text = Mathf.Abs(_currentVelocity).ToString("F") + " m/s";

         if (realVelocity < 2.5)
         {
            velocityText.color = Color.red;
            velocityText.text = Mathf.Abs(_currentVelocity).ToString("F") + " m/s";

         }

         if (realVelocity > 3.3)
         {
            velocityText.color = Color.green;
            velocityText.fontSize = 50;
            velocityText.text = Mathf.Abs(_currentVelocity).ToString("F") + " m/s";
         }

         else
         {
            playCreek();
            velocityText.color = Color.white;
            velocityText.text = Mathf.Abs(_currentVelocity).ToString("F") + " m/s";
         }
        speedLine.material.color = new Color(1,1,1,lineColor);
    }

    void playCreek()
    {
        creek.Play();
    }
}
```