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Rowing Reimagined Extended

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Abstract

This thesis describes the development, design and validation of the rowing reimaged virtual reality research platform. This platform aims to make rowing research in VR possible. It does so by adding features into an existing platform such that new research opportunities can be explored within movement science. The design of this platform is outlined and validated by movement scientist performing research with the platform and a user experience evaluation. The platform in its current state is ready and available for use. There is still improvement to be had mainly in game and user interface design. Nevertheless, many research opportunities can already be explored.

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1 Introduction

Movement is an important part of life. It can provide both physical and mental health benefits, and improve the overall quality of human life.[Ruegsegger and Booth, 2018] As such, movement scientist dedicate their time to research how people move and how to enhance human performance.

An ideal setting to research movement is to observe humans as they naturally engage in sport activities, from going on a simple jog to playing an intense soccer match. Capturing data in these natural environments can be difficult. The devices used for the collection of this type of data can impede movement if they need to be carried along, or they might be damaged by outdoor conditions such as rain or wind. Therefore, simulating outdoor activities within an indoor environment can be used as a replacement to research human movement. The movement of an outdoor activity can be captured for sports such as running, rowing and cycling by ergometers that replicate the movement without moving forward.

The ergometers can serve as a replacement for the movement, but can not capture the experience of a race. Athletes push themselves further within a race then they do during an indoor training or rehabilitation. The lack of this experience can result in an athlete being declared recovered, but in the next match they would encounter the same issue again. Sports interaction technology (I-tech) may be able to better recreate an environment in which people push themselves further.

Sports I-tech can enhance performance, engagement and learning within many sports.[Postma et al., 2022] They can be used to reintroduce aspects that are lacking in

the current indoor replacements. Sports I-tech is technology and software that can be used to improve exercise. It can be as simple as a smart watch or as complex as a interactive training court. The technology that this paper focuses on is virtual reality (VR). The main advantage of virtual reality is that someone can be put in a virtual environment. The virtual environment can be made realistic such that things in the virtual world can be introduced that feel real. A practical use of this is in exposure therapy for phobia treatment. Where the phobia is displayed in the virtual environment to expose a person to it.[Miloff et al., 2019] For sports VR can similarly be used to recreate the natural environment in which a sport is performed.

Within movement sciences research is often done on the cyclical sports of running, cycling and rowing. These sports can be researched using ergometers in a lab setting and could thus benefit from a virtual environment. From these sports rowing could benefit the most from a virtual recreation of the outdoor activity. Testing on the water is difficult as any data collection needs to be done with waterproof electronics. It is also a sport that uses muscles trough out the whole body and is thus interesting for movement scientists.

To perform research on rowing in virtual researchers need to set up experiments. This involves creating a test setup substantiated by research. To establish a test setup, literature research is employed to identify a gap in knowledge or to find something that needs to be cross-checked. From this research constructs are identified that need to be tested. In a test setup the constructs are operationalised, separated in such a way that you can manipulate an individual construct.[Hoffman and Zhao, 2020]

A test setup is often shaped by the tools that

are available to the researchers. In movement science and computer science, Researchers are restricted by the available technology. In some cases, they can rely on readily available products. In other cases they need to make the technology themselves. For example, Ruffaldi et al. [2009a] made their own highly detailed test setup. In most cases however, researchers opt to use either the Concept 2¹ or RP3² rowing machine.[Hoffmann et al., 2014, Murray et al., 2016, de Campos Mello et al., 2009] The availability of the technology can influence the depth of research that can be completed.

What research setups can be made depends on the validity of the setup. Validity comes in several types: external, ecological, internal and construct validity.[Hoffman and Zhao, 2020] External validity makes sure that findings generalize beyond the specific study setup. Ecological validity ensures that findings can be applied to real works situations. Internal validity ensures that results are only impacted by the construct of interest. Construct validity ensures that results give more information about the constructs of interest. To retain this validity, researchers can use well defined measures and research setups that have been used before and are well defined. Information to replicate a research setup is often included in a paper. However, when working with technology the exact program is not often shared publicly as it was made for a specific purpose.

Research platforms can provide a way for different researchers to use the same setup for different tests. A research platform in this context is a technology or software aimed to assist in research. When a research platform is used often

it is tested and validated for external and ecological validity. While internal and construct validity are created by adaptability and robustness of the platform. Such that researchers can adapt the platform to a construct of their need. Examples of research platforms include the Furhat robot that can be used for social human robot interaction.[Al Moubayed et al., 2012] And the Praat platform, used within linguistics to analyse, manipulate and synthesize speech.[Boersma and Van Heuven, 2001]

This paper focuses on the development of a research platform for rowing in virtual reality. This falls within the scope of the rowing reimagined project between the Vrije Universiteit Amsterdam and University of Twente. This project was already ongoing and developed a VR rowing simulator, that could have multiple rowers in a single boat row down a river in VR. The starting platform will be discussed in section 3.1. This paper discusses the expansion of this program to a research platform. It does so along the following research questions:

Q1: – What features make for a usable VR rowing research platform?

Q2: – What contributes to the research opportunities of a VR rowing research platform?

The first question is based on the concept of usability. While usability is hard to define, it can be seen as the absence of problems in using the product. Thus, it can be used effectively, efficiently, and with a feeling of satisfaction for its intended purpose.[Lewis, 2014] To test for usability, usability tests can be performed on a program.

¹<https://www.concept2.com>

²<https://www.rp3rowing.com>

The second question relates to the needs of the target group. What is the type of research they need to perform, and what are important details within the domain. This includes what type of features are important, but also the level of realism of each feature. This is tested in two ways, through identifying trends in literature research and conforming these trends with experts on the domain.

This paper first discusses related work in sports interaction technology, rowing research and research platform. This discusses what the technology can be used for in research and what features it should include. Secondly it will discuss the development of the platform. It outlines what the starting platform is and then shows the development guided by three projects. Next, the final design of the features chosen is discussed. Afterwards the platform is validated with an evaluation. Next the results to the posed questions above is discussed. Lastly, a conclusion is given about the future of the platform.

2 Related work

This section outlines related work on three topics. Firstly, sports interaction technology and what it can be used for is explored. This outlines how technology can be used in sports research. Secondly, recent rowing research and adjacent sports such as running and cycling is discussed to determine what can be included in the platform as research opportunities. Thirdly, a few research platforms are discussed on how they are structured, this indicates what should be included in a platform. Lastly, all topics are discussed specifically on their importance for the platform developed in this thesis.

2.1 Sports interaction technology

Sports interaction technology (sports I-tech) is technology used for new training methods. The technology can be a simple device such as a smart watch, or an apparatus as complicated as a smart training court. Many sports can benefit from new technological developments to enhance performance engagement and learning.[Postma et al., 2022] To create a new way of training using technology, research needs to be done into what makes good interaction technology. This involves interdisciplinary research, because information for development comes from multiple disciplines. Computer science, engineering, sports sciences and health sciences are all involved. While collaborative research is on the rise it is still not without its drawbacks.[Dalton et al., 2022]

Research in sports I-tech is done in two contexts: training and lab. Within the training context, the technology is tested on its ability to assist in training. This is to see in what way it can be deployed and in what way it can be most effec-

tive. Within the lab context, research focuses on the fundamentals of human movement. It uses the sports technology as a medium to perform research, rather than determining its effects.

In a training context, sports I-tech is tested on its effectiveness to assist in training. This can be to test if a new technology can be used, or how an existing technology can be optimised to allow for the best training. This research focuses on isolating the technology as a construct. For example, Hoffmann et al. [2014] isolated VR in the context of improving rowing performance. In their case, they used VR to show a pacing boat in such a way that a participant could train to optimise their pacing. Using several conditions they isolated VR and showed that it can be used for training. Furthermore, Sigrist et al. [2015] focused on investigating what type of feedback would be most effective within a room wide projected rowing simulator. They investigated if visual feedback can be improved with haptic and auditory feedback. Attempting to find what way the technology can be optimised for training.

Training research shows why and how a technology can be used in training. Using results from this research can assist in applying the technology to real world training. For example, to practice technique or pacing. Additionally, this research has the added effect of increasing the validity of using the isolated technology for fundamental research within the domain. This time of research is thus important to both improve the way technology assists training as well as enable fundamental research using the technology.

In the lab context fundamental research using sports I-tech is performed. This researches uses the technology to eliminate external factors to explore one concept in human movement science.

For example, Fadde [2006] used sports I-tech to isolate the concept of perceptual decision

making. Perceptual decision making is a subconscious process that people use when reacting to a visual event quickly. In the study they used baseball as the sport of choice. In real world settings isolating the decision making is difficult to achieve as the decision on where to hit the baseball is already made before the researcher can ask for feedback. Fadde [2006] instead opted to create a game where participants had to quickly predict a pitch. By putting this sports I-tech in they could research a fundamental concept.

Similarly Murray et al. [2016] used virtual reality to isolate the effects of partners on rowing. Their test setup controlled for both the effect of VR and the effect of a partner. Immediately ensuring that VR can be used for training alongside isolating the effects of partners in a lab setting. Research is often involves for both lab and training context, and both combined contribute to the overall validity of each system.

In this project Virtual Reality is the main technology of interest. Murray et al. [2016] shows why VR should be utilised and why it is used in this project. VR can be used to create a consistent research setup that would not be able in the real world. A human partner would introduce variability in the test setup. But a virtual partner can be made to function the same each time for each participants.

Additionally VR can be used to create a realistic looking scenario. By immersing someone in a virtual environment they will gain a sense of presence. Presence refers to the psychological sense of 'being there'. [Slater et al., 1995] Presence is influenced by immersion and realism of the system. [Newman et al., 2022] This can help to create more realistic replications of environments for research. It is also used for exposure therapy for its controlled realism. [Miloff et al., 2019] Within movement science this enables re-

searchers to recreate scenarios that normally can be difficult to create in the real world.

Using the improved realism and control sports I-tech brings, new test setups can be created. This is a multidisciplinary task, requiring engineers and computer scientist to develop from the ground up. It also requires researchers from the domain the platform is made for to shape what research opportunities are included in the platform. Working together ensures that the platform can be used upon completion.

2.2 Rowing research

This thesis focuses on expanding a VR rowing system to include new research opportunities and make it easy to work with for researchers outside of computer science. This platform is an expansion on a system that was developed within the rowing reimaged project. Which in turn is a continuation of work done in VR4VRT.[van Delden et al., 2020] The platform already included a way for rowers to row on an RP3 ergometer with a VR head mounted display. The movements of the machine and the speed of the flywheel are then translated to the virtual world. A rower could then row in the virtual world on a river.

To identify research opportunities, current research was identified through literature research. This section outlines the identified trends. Rowing is the main focus of the literature, however other cyclic sports are also included in the exploration. Cyclic sports are sports that require repetitive movement, such as running, cycling, rowing and swimming.[Lorenzo Calvo et al., 2020] For this research only the sports that include an ergometer option are considered, thus running (treadmill), cycling (exercise bike) and rowing (rowing machine).

Each research opportunity has to have at least one paper published within the last five years (2018-2023), with at least one other paper within the last 10 years. These restrictions have led to three main research opportunities being identified: competition, movement and feedback. Each of these opportunities have sub-opportunities, giving a more detailed direction for development.

2.2.1 Competition

Competition is an integral part of many sports. Competition can exist in several facets such as a team playing against another team, as individuals competing with other individuals or even as friendly banter between teammates. Competition has been a long studied subject, with published papers going as far back as 1898.[Triplett, 1898] Their work already focused on two main aspects of competition: opponent competition and partner competition. Later, with new technology self-competition was added. These three aspects are discussed in this section.

Opponent competition happens when you are in a race against the people you are competing with. Your performance is actively equated to what place you get in the race compared to the others competing. In football for example this competition arises because only one team can score the most goals. In rowing this competition arises between boats, as only one boat can be the first to the finish.

Having someone else around has been shown to increase motivation and enjoyment.[Peng and Crouse, 2013] Additionally, competing with someone can improve performance.[Corbett et al., 2012] Competitiveness is however different from person to person. Some people show high competitiveness, while others can remain indif-

ferent to competition.[Anderson-Hanley et al., 2011]

Recent work on opponents, such as the work by Parton and Neumann [2019], looked at some aspects of opponents using virtual reality. They made a virtual setup with a moderately challenging competitor and an extremely challenging competitor. By having participants immersed in a virtual reality rowing setup, participants were able to row against these controlled opponents. The research showed that extreme competition can be detrimental to performance.

Opponents are not the only classical way to invoke competition. Partners can also invoke competition. Partners are the people you train together with or are on the same team as. In rowing these are the people you share a boat with. However, it can also be a pacing boat giving you a comparison to maintain proper pacing.

When training with partners, people are affected by the Köhler effect.[Feltz et al., 2011] This effect states that individually underperforming people are more motivated in group tasks. This effect makes partners an important aspect of training.

Feltz et al. [2020] recently looked into the effect of using virtual partners in cycling, looking at how the rate of superiority affects training. In their research only the always better partner reached significant results over the control. Hamada et al. [2022] worked on partners in jogging and the level of realism they should achieve. They used an augmented reality approach in which they discovered that while human partners are preferred over virtual partners, higher fidelity virtual partners are preferred.

For rowing in particular Murray et al. [2016] worked on partners during a VR rowing exercise. It showed that partners can improve rowing performance. However, external factors could

have played a role in this. Such as the case of modelling.[Postma et al., 2022] In which case someone would learn optimal pacing strategies if given an example. Those in the group without an example would not have learned it. The effects of Murray et al. [2016] trying to convince the participants that the partner rower was a real person rather than virtual also could have impacted the research in unforeseen ways. This leaves many opportunities still untouched within the field.

Beyond partners and opponents, a type of competition that can be uniquely used by digital exercise systems exists. Self-competition is competition against your own past performances. In traditional sports this can be found in records of past performances and personal bests. In digital sports, particularly in exergames, this can be expanded upon. Bahrin et al. [2022] provide a review of self-competition in virtual reality exergames. Showing that several researchers have recently worked on the topic.

Self competition in daily life can also be recorded by use of sports technology. Smart watches now keep a record of each day's workouts. This provides records to compete against. The work by Peng and Crouse [2013] worked with these records in the play domain of exergames. Their work focused on the difference between self-competition against a pretest score, cooperation in the same physical space and competition in separate physical spaces. Their work explored all different facets of competition. They found that opponent competition in different spaces resulted in the highest enjoyment and future play motivation.

A unique way of self competition in games is through a concept called a 'ghost' system. A ghost is a recorded past attempt at the task, that is played back during the current attempt. This

can be a modified ghost. For example the work by Michael and Lutteroth [2020] made a system in which past ghosts are shown in a VR cycling environment. They also introduced the concept of a future ghost. The future ghost performed slightly better than the person along the upward trend of the participant’s training. This method is similar to what Parton and Neumann [2019] used to create competitor and Feltz et al. [2020] to create a partner.

All in all, the ways to elicit competition have overlap in their technical design. Opponents, partners and self competition can all make use of the same system. The difference is how the researcher introduces any virtual avatars in the test procedure. The depth and recent research on competition shows for it to provide many research opportunities to the platform.

2.2.2 Movement

In any sport the way you perform movement can affect your performance. A good technique is important for better performance and power output. But it is also important to prevent injuries.[Arumugam et al., 2020]. Pacing can improve race performance. With different strategies resulting in different outcomes.[Hoffmann et al., 2014]. Lastly, for rowing specifically, the team can play a role in how you move in the boat. As there are multiple people in a boat, each contributing in their own way to the forward momentum and the balance of the boat. These three facets, technique, pacing & team rowing, were also discussed by Ruffaldi and Filippeschi [2013] as they were developing a training platform for VR rowing.

Technique involves the way someone moves their body during exercise. In rowing this commonly consists of four phases of the rowing

stroke: the catch, drive, finish and recovery.[van Delden et al., 2020] These phases are always performed in this order and can overlap. They guide the training of technique in rowing. Kojić et al. [2019] focused on the breathing aspect of the four phases. As breathing synchronises with the drive and recovery phases. Exhaling during the drive and inhaling during the recovery. Another important part of rowing technique is the oar movement. The oar movement should follow a certain trajectory to optimise overall performance.[Ruffaldi et al., 2009b, Sigrist et al., 2015]

Pacing is an important aspect of any racing sports. Pacing is the distribution of power during the game. In rowing, for example, you can have a slow start, to preserve energy for later. Alternatively a rower can have a fast start but fall off later on. ideally you have no energy left at the end of the match. As this would suggest optimal performance. This is also known as energy management.

Proper pacing can improve performance. For example in the research by Hoffmann et al. [2014] they had novices learn a quick start pacing strategy using VR. The group that got no further instructions had worse performance than those who did not get pacing instructions. By default both groups started with an even pacing. Pacing strategies have also recently become more important. Because the 2028 Olympics have changed the race length from 2000m to 1500m due to challenging logistics at the Los Angeles venue.

There is still not full agreement on what is consider optimal pacing. Boillet et al. [2022] recently attempted to find the optimal strategy for 1500m and 2000m races. They however ran into issues with data collection and forcing rowers to row at a pace different from their usual trained pace. The fast start strategy was disliked most by participants, however this is the most com-

mon strategy in competition. Other aspects that influence the advantages of pacing strategy were also not captured in this research. As relative position to other competitors also influences performance. VR is better able to replicate this.

VR can also be used for team rowing exercises. Team rowing is when multiple people are rowing within the same boat in the same race. Up to eight rowers can be in a boat at the same time in normal races. This is a unique aspect of rowing, as not many other sports have multiple people active propelling the same vehicle. Rowers have to work together to move forward and keep the boat balanced. Balancing is something that is yet to be captured by ergometer technology.

To propel a boat forward, rowers need to have some form of synchrony with each other. Most commonly this is done by in-phase rowing. Thus each being in the same stage of the rowing stroke. There are several papers that show systems to show investigate synchrony out on the waters, such as the works by Cesarini et al. [2014] and Liu et al. [2023]. Using VR, Varlet et al. [2013] worked on interpersonal coordination. they tested if coordination with a virtual partner could be transferred to that of a human partner. They found that it could be transferred, but coordination was better with a human. They suggested improvements in the virtual partner, however human partners over the internet could also be used.

Incorporating movement based features will assist the platform to also be used for research for sports I-tech in the training context. As research within this field often focuses on optimising training. Additionally, creating opportunities to recreate scenarios such as races allows for research into the psychological aspects of the movement.

2.2.3 Feedback

Feedback is a field of research that focuses on how and what information to give to someone to improve at a certain task. For digital technologies, feedback has only recently been mapped out. As new technologies are developed, new facets of feedback are able to be explored. Postma et al. [2022] have create a taxonomy of sports interaction technology. Aspects of feedback are also discussed within this taxonomy. The taxonomy splits feedback into timing, modality, frequency and content.

Within this split, modality is the aspect that is most defining in feedback research. The modality is split in visual (perceived by the eyes), auditory (perceived by the ears), haptic (perceived by touch) and multimodal feedback (perceived by any combination of senses). Of these types of feedback, haptic was not identified as a research opportunity as it did not have recent research within the specified domain. However it is still included within multimodal feedback. This split has also been used by Sigrist et al. [2013] to split feedback research on the topic of motion learning.

Visual feedback is the most common feedback in the VR space. VR is first and foremost a visual immersive technology. Audio and haptic feedback are included using speakers and controllers. However these are not generalised to all types of VR. Within running some research is focused on how avatars can serve as guidance to a person. Willaert et al. [2020] used an avatar to show an example proper gait to a person. This in an attempt to model the gait of that person. They gave the participant an ownership illusion over the avatar, by having the avatar mirror the participant's movements at first. During the task the avatar would move according to

proper gait to model a participants movement. Results were not statistically significant but it leaned towards being able to model someone’s movement trough this visual feedback. Additionally, avatar feedback was given by Hamada et al. [2022]. Who researched the realism of the avatar necessary for the avatar to be able to assist a person in walking.

Kojić et al. [2019] have also worked on ways of giving visual feedback specifically within rowing in VR. They focused on giving visual biofeedback of the rhythm of a participant in contrast to the optimal breathing rhythm while rowing. They used two separate types of visual feedback. One was by a graph, which gave an abstract representation of breathing rhythm. The other was by an animated lung, which showed a more natural aspect of breathing rhythm. Both types showed improvement over the baseline. However, in this experiment the feedback took up a large part of the visual view. They suggest future research on reducing the interface, as well as the need to inspect different modalities of feedback.

Auditory feedback is similarly a large part of research in the digital domain and the sports domain. It can be split up in two categories: alarms and sonification.[Sigrist et al., 2013] Alarms provide feedback by playing a sound when something happens that needs to be corrected. Alarms have not been used in recent studies. Sonification, however, is a common aspect in research. Sonification is the process of creating sound directly from data. van Rheden et al. [2020] provided a literature review on sonification for sports in the past decade. The review includes papers related to the cyclical sports. The majority of papers in their review focused on making an athlete aware of their motion.

An example of sonification is the work by Landry et al. [2016]. They sonified heart rate

during cycling to music at a comparable beats per minute. They found this to improve motivation. Similarly, Schaffert et al. [2011] sonified rowing velocity to a pitch. This sonification improved technique and pacing of rowers as measured by mean velocity. These two works were done without virtual reality. The work by Landry et al. [2016] allowed participants to watch TV during a cycling exercise. This was however not an attempt at VR, but rather an option for participants as they tested the sonification of heart rate.

Within the domain of VR and movement, there is research on sonification within teleoperation. Bremner et al. [2022] studied the effects of diegetic and abstract sonification on the presence and task load of teleoperating a robot. Diegetic sounds are generated sounds that are natural or established for the environment. In the case of teleoperating a robot in a possibly dangerous area, the sound of a Geiger counter was used. Abstract sounds are sounds generated from the data in the environment, but are not present normally present in the situation simulated in VR. They concluded that diegetic sounds improved task performance by decreasing workload. On the contrary, abstract sounds created a more stressful task. Neither impacted the presence a participant experienced.

Lastly, multimodal feedback combines one or more feedback modality. Each modality on their own can contribute to a user staying engaged and motivated within sports. Using multiple modalities at the same time can improve motivation further. Greinacher et al. [2020] continued with the work by Kojić et al. [2019]. They expanded the system to be able to give haptic guidance for breathing. They found that haptic guidance improved synchronicity. However the user experience was rated worse than visual feedback only.

Similarly Sigrist et al. [2015] worked on audiovisual and visuohaptic feedback for oar trajectory. Visual feedback was shown by means of a superimposed target oar trajectory on the projected screen. Auditory feedback was provided by sonification of the oar movement. Haptic feedback was given through guidance in the oar movement. As the oar in the research setup could be inhibited to correct the movement. They found that the audiovisual group performed the best. However both groups significantly improved over the control. Multimodal feedback allows for a development loop within research. Multimodal papers often suggest further research into specific modalities. Additionally, papers on the specific modalities suggest research in multimodal methods.

Feedback is a broad concept without one way to do everything. It is heavily dependant on both data and the technology that can provide the feedback. But also involves artistic freedom in how to properly give it form. Feedback is both a scientific and artistic process that is quite open ended. Every single piece of feedback will appear unique as the art changes, but the scientific basis remains. This leaves much room for future research, but due to the artistic nature it might be better to enable feedback rather than implement it.

2.3 Research platforms

The definition of a research platform for this paper is technology or software built to support research within a specific niche. The platform has settings that can be changed to fit different research questions within that niche. Research platforms usually are developed when a researcher needs to be able to research a subject that is often repeated. The programs and setups

they make can sometimes be expanded for more general use. For example Filippeschi et al. [2009] has described their setup over a variety of papers as well as the additions they made to it. Their platform however does not use off the shelf physical components. It rather uses an engineered setup. Thus, recreating the setup requires technical knowledge.

Research platforms do not yet have a standardised method on how they are to be presented in a paper and what is important to be included. This paper presents a research platform and takes inspiration from the structure of other platform papers. These structures show what is considered important to be included in a platform, as well as how to validate it. For this, two research platforms that have a single introduction paper are discussed: Praat and Furhat.

Research platforms have been created in different domains before. Praat, for example, is a program developed for linguistics.[Boersma and Van Heuven, 2001] It is a platform that mainly focused on analysing speech. This used to be a task done by hand that would take a lot of time. The platform was made to make linguistics research easier and quicker, by allowing more researchers and researchers from different domains to employ the system in favor of manual labour. In the paper the creator describes the variety of features it has and a user review of the platform. This is done to outline both the possibilities, and also ground the possibilities in the fact that someone has used it.

A research platform within the social robot domain is the Furhat robot.[Al Moubayed et al., 2012] The Furhat robot is a combination between a research platform and a commercially available product. The Furhat robot is a standing head with a projected face on it. It can be used for research on how people interact with robots. In

the introduction paper, the creators show the development through research. Each feature had individual research performed on its effectiveness. The paper also gives an example application of the Furhat robot. Similar to Praat, the Furhat platform is grounded in how it can be used. But the Furhat paper focuses more on how individual features are grounded.

The papers discuss feature rich platforms, focusing for the majority of the paper on what features are included. So a broad feature scope is important in a platform. For validation of a platform it is considered important that someone other than the developer is able to perform research with the platform. A research platform can thus be a good platform if it is rich in features and validated by other researchers.

2.4 Requirements for a VR rowing platform

The previous sections discussed the specific aspects that go into a VR rowing research platform, sports I-tech, rowing research and research platforms respectively. It shows the possibilities of research that it might be used for. How sports I-tech can be used in research is discussed in section 2.1. Sports I-tech can be used in a training space and a lab space. The focus of this platform at this stage is on its use in a lab space. The focus is on fundamental research within the movement sciences, rather than verifying if VR can be used since it is a shared project with the movement sciences research group at the VU. The platform does not rule out the use as a training space, but it is not the focus of development.

The platform needs to be feature rich. This means it can be applied to a large variety of research within its niche. The research it should be applied to has been determined in section

2.2. Features should be made such that they apply to more than one opportunity. Opponents, partners and self-competition, is a good one to start with for this. These opportunities can use very similar features. The explanation of the researcher differentiates between them, rather than the feature in the platform. Movement opportunities will also likely come from the features that are developed for competition. As virtual partners and opponents are often used for pacing and technique training. Feedback is more difficult to include as it has very specific uses that can not be generalised. Which features exactly are chosen are further discussed in section 3.2.

A good research platform needs to be validated. The previous platforms discussed in section 2.3 show that validation by others is important. This means that the target group is able to do research with the platform. An important factor of this is that the platform improves upon the current way of doing research, which can be done either by reducing the amount of labour a researcher has to do or by creating new research opportunities that did not exist without the technology.

3 Development

The previous section discussed related work, guidelines were set for what needs to be included in the platform. Development of the platform was planned to be an iterative process in which some features have to be prioritised over others. As this project is a continuation of a bigger project, the first section discusses the existing platform at the start of this thesis. This shows what features already exist. Then it discusses the development strategy employed. This iterative process is along three projects at the VU, which serve as a way to prioritise features by needs of the project. These projects, their requirements and the issues encountered are discussed per project. Lastly, there is a discussion on the process of development.

3.1 Starting platform

The existing platform at the start of this project contained a rowing simulator in virtual reality. This specific platform was built in the social video game NeosVR³. NeosVR allows for in-world programming with the Logix visual coding language. Within NeosVR users can join in on the virtual worlds of other users. This creates the ability for anyone anywhere around the globe to join the same virtual world as you. On the platform this feature allows for multiple rowers to join. The world consisted of a river, a dock and mountains as environment to block a rowers vision to the existing environment. The dock in the original world can be seen in figure 2.

The physical setup can be seen in figure 1. There are two RP3 rowing machines, each tracked using three trackers. One tracker is on the front of the flywheel, one tracker is on the

³<https://www.neos.com>



Figure 1: The physical setup of the platform

handle and one tracker is on a bar attached to the seat. These trackers are tracked by virtual reality base stations. The RP3 is also connected to a computer through USB to extract the flywheel data. To that same computer the VR headset is also attached and NeosVR is running on that PC. Extra participants need the same setup with another computer.

Virtual RP3 machines allowed for calibrating the trackers attached to the physical RP3 rowing machine. Using the trackers, the relative movement of the machine can be replicated in VR. Using the RP3 USB data from the flywheel is translated into boat velocity in the virtual world.



Figure 2: The dock of the existing environment at the start of the thesis.

To represent the virtual body of a participant there are two avatars present on the dock. These systems translate all movement from reality into the virtual world.

When everything is set up, a rower can enter the boat. The boat can be set to any amount of rowers that might be necessary. When all seats of the boat have been filled, rowers can row on the river after an editable starting delay. The river infinitely generates the next part of the river. In this way a boat can row forever if necessary. To set the length of any race there is a menu present on the dock that can be set to a time trial or a distance race. Rowers will then row for either a set time or a set distance, and after completion the rowers will automatically be transported back to the dock.

The platform includes a websocket to get data in and out of the system. The RP3 interface⁴ receives flywheel data from the RP3 trough USB and sends that data to NeosVR. Consecutively, the Websocket logger⁵ receives and stores the data that is collected within NeosVR on the rowing activities in comma separated values (csv) format. Lastly, there was a user guide to be able to use the platform⁶.

The platform enables basic rowing research with participants sharing a single boat. However, it does not tap into many of the research opportunities of rowing yet and allows for little adaptability without going into code. Thus, it

⁴<https://github.com/marsmaantje/RP3-Interface>

⁵<https://github.com/marsmaantje/WebsocketLogger>

⁶<https://github.com/marsmaantje/RowingReimagined>

needs to be expanded upon to become a feature rich research platform that anyone can use.

3.2 Development strategy

As a development guide, three movement science projects at the Vrije Universiteit Amsterdam (VU) used the platform. For each of these projects new features are implemented. The students within these projects also received technical (tech) support to assist with any issues that arose. Feedback from these support sessions are used to improve the project. The first project started at the time that initial development of this thesis started. Thus new features were not yet present.

To expand upon the starting platform an iterative development strategy was taken. First, a feature is identified. Then it is grounded on what opportunities and usability it should achieve. Then the feature is implemented. Lastly, the feature is validated by the project. Then a new feature is identified, and work proceeded with the new feature.

The features to implement are identified using two methods. The first is by translating research opportunities to features. The second is by input from movement science projects and experts. Together they shape the requirements of the chosen features and also assist in validating them.

Within feature implementation, each feature was first implemented with the minimum needed functionality. When it fits the needs of the project, it is used within the project. Using the feedback from the alpha testing that the projects performed, the feature is expanded to fit broader research. The expanded feature then is included in the next update of the platform.

To show the process of development each of the projects is discussed by a description of the

project and the requirements, the features implemented in the platform, usability problems encountered during development, the final setup for testing and critical problems that need to be resolved by the next project.

3.2.1 Project 1: metronome rowing

The first project aimed to use a form of a metronome to assist rowers in matching to a predetermined strokes per minute. To do this they required a way of giving a visual metronome within the program. They also required this to be possible for multiple rowers at the same time. Because the physical setup used connected rowing machines.

To give the visual metronome the animated avatar is designed. The avatars can take a seat in a rowboat and can be animated at a set strokes per minute. Thus, serving as a metronome. To enable this for two rowers at the same time another boat was added. This way each person could sit in the bow rower position and the stroke rowers were filled with avatars. A developer room to be able to control the avatars and the race was also added.

Two issues were encountered in the project: animation timing and developer room location. Firstly, the animation was erroneously designed to be unrealistic compared to real rowing. This was resolved by having the students on the project judge the realism of the animation themselves. The students were rowers, and thus knew a realistic timing of drive and recovery. Secondly, The developer room platform was placed floating above the river, such that a researcher could easily see the boats. However, this location casts a shadow on the rowers and was not easily accessible. Its location is changed by the next project.

In figure 3 the world can be seen that was

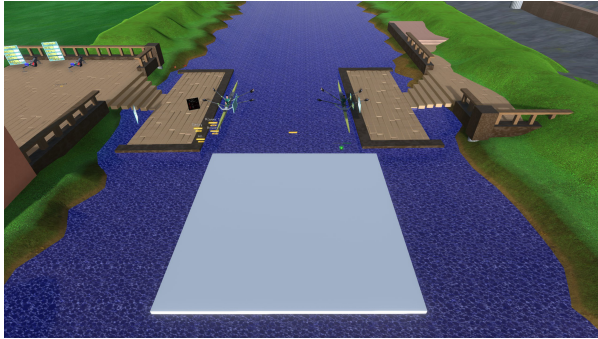


Figure 3: The dock the first project used to test

used to test. It had the developer platform floating above the river, two separate docks and two boats. It also had settings to start the metronome. Animated avatars could be added to seats in the boat.

The critical error encountered during this project was that the starting criteria for the boat to start moving forward were broken. The boats were stuck at the dock and would not move. This is caused by the avatars breaking the starting requirements of the original boat. The starting requirement was based on a user entering the boat. The additional boat caused similar problems as it was not possible to start both boats at the same time. The last error that contributed to this was an error in which the clock for the race did not start. This is resolved before the next project, but was not during this project.

3.2.2 Project 2: anti-phase rowing

The second project aimed to research the effects of visual and physical phase difference. In this project the rowers are once again physically connected, but in the virtual world visual feedback needed to be given that was different from the physical feedback. The visuals should show for both rowers that they are in the bow position.

However, the stroke position is visually occupied by the other rower at a delay.

To enable the visual feedback, the animated rower got a new option. Using this option the avatar copies another rower or avatar in oar rotation and seat location. This animation can play the movement back after a delay in seconds. A new menu to input these values is added in the developer room. Additionally, start and reset buttons are added in the developer room to start and end the race.

Two larger issues were encountered during this project: tracking failure and NeosVR storage. Firstly, the tracking system of the physical machine is prone to failure due to fast movements and occlusion. If tracking fails at the oar tracker, the virtual oars would go to an unrealistic position. The block of the machines, or the black tape on the RP3 at the VU research setup might have also impacted the laser based tracking further. In this project, the issue was further expanded due to the avatars copying the error as well. Partially this could be solved by positioning the base stations to minimise occlusion. The bigger issue can be solved using Data filtering. But the issue is not common enough for it to be a priority.

Secondly, NeosVR has some issues with storing the world on the accounts at the VU. NeosVR only has user guides made by the community. Thus, it is difficult to find information on how to use the game. The research setup for the project needed the student to set up a wall in the world to block vision between the participants. Without being able to save, the student needed to set this up each time. A compromise was made to store the world with the wall for the use of the researcher separately. The saving issue is resolved at a later version. To resolve the information issue, a user guide will be made.

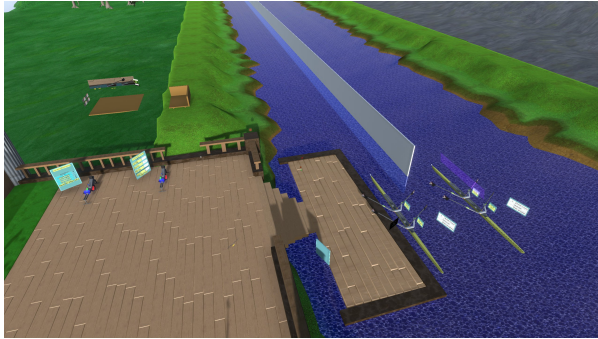


Figure 4: The dock the second project used to test

In figure 4 the world can be seen that was used to test. The developer room has moved and the second dock removed. The boats are closer to each other, but separated by a wall such that the rowers can not see each other while rowing and will only see an animated avatar.

There were no critical errors encountered during this project. During the testing the student no longer needed any technical support.

3.2.3 Project 3: effects of opponents

The third project aimed to research the effects an opponent has on the performance of a rower. In the setup they plan to record a baseline time. Then for the second trial an opponent boat finishes at that baseline time.

To enable this the boats got a new setting using which it moves independently of a human rower. These boats are referred to as AI boats, as they do not have a human rower in the boat. The AI boats can be set to finish at a certain time. To input the data for the AI boat a boat menu is added to the developer room.

Within this project more technical support was needed than usual. The technical support involved both explanation of how to use the increasing number of options and steps for setup,

as well as technical support for the physical setup. This student reported being less experienced with technology. The issues they encountered were mainly in usability of the platform and usability of the physical setup. To reduce expert help needed, attention was given to the usability of the platform. Additionally, the user guide was expanded upon.

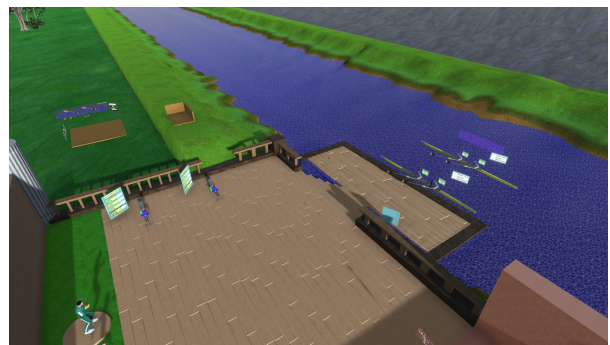


Figure 5: The dock the third project was supposed to test on

In figure 5 the platform can be seen that was originally delivered to test with. There are little visual changes besides the missing wall as that was not necessary for this project. Most changes for this program were in code for the AI boat.

The critical error encountered in this project was the unrealistic movement of the AI boat. The AI boat was made to function as a conveyor belt, meaning that it moves at a constant speed from start to finish. For the research the student wanted to make use of all stressors an opponent can deliver, which includes overtaking behaviour. This was not possible as the boat would start too quickly and thus be far ahead of the human rower by the time they had sped up to their maximum speed. This project has not yet concluded at the time of writing this thesis. The project might use another feature implemented

independently of the projects, which allows the AI boat to match another boat and go slightly faster or slower than that boat.

3.3 Discussion of development

Features for development are mainly chosen per the requirements of the projects. At first the focus was on adding research opportunities and adding features in a cycle per opportunity. From the projects however it became clear that the research opportunities were not addressing the main need of the target group. The target group was looking for a quick to learn platform as time constraints was a main concern. Adding more opportunity features was complicating the system. Thus, it took longer to learn and the setup became more difficult.

This changed the focus of development to mainly incorporating features for ease of use. This includes editing the features for research opportunities to be more generalised and easily changeable. Allowing researchers to use the platform without any knowledge of coding became a necessity. As learning both the platform and the underlying game NeosVR takes a lot of time, and could turn away researchers from using the platform. Thus, after completing the animated avatars and the additional boats, the focus shifted to improving existing features. These improvements mainly focused on usability.

These features were not put as requirements by any projects. Research projects focused on research opportunities. Usability features are less defined than the opportunity features. The developer room in general is a usability feature that is a congregation of all menus added for usability. Most of the usability features are improvements upon already existing features. What exactly the features are is discussed in the next section.

4 Design

This section describes the design of the features at the end of development. In figure 6 a birds-eye view of the world can be seen. It is shown in the large river variant with the developer room on top of the ledge. This section discusses the features along two categories: research opportunities and usability. Afterwards it shows the architecture of the main features. Lastly, it discusses some features that were not completed by the time evaluation started, but are recommended to be included in a future iteration of the platform.

4.1 Added platform features: research opportunities

Two research opportunity features have been added: animated avatars and extra boats. These features were chosen as they fit the need of the projects as well as allowed for a wider variety of new research. Each section discusses the details of how the final feature works as well as reasoning for decisions. It first discusses the research opportunities that the feature is made for. Then it discusses the technical implementation of the feature and the menu in which the settings can be made. Lastly it discusses some drawbacks that the current implementation has.

4.1.1 Animated avatars

Animated avatars are avatars that replace a human rower, allowing for research with multiple rowers. These animated avatars can be placed within the same boat as human rowers to function as *partners*, as well as in other boats to function as *opponents* as discussed in section 4.1.2. The avatars are designed to be full characters,

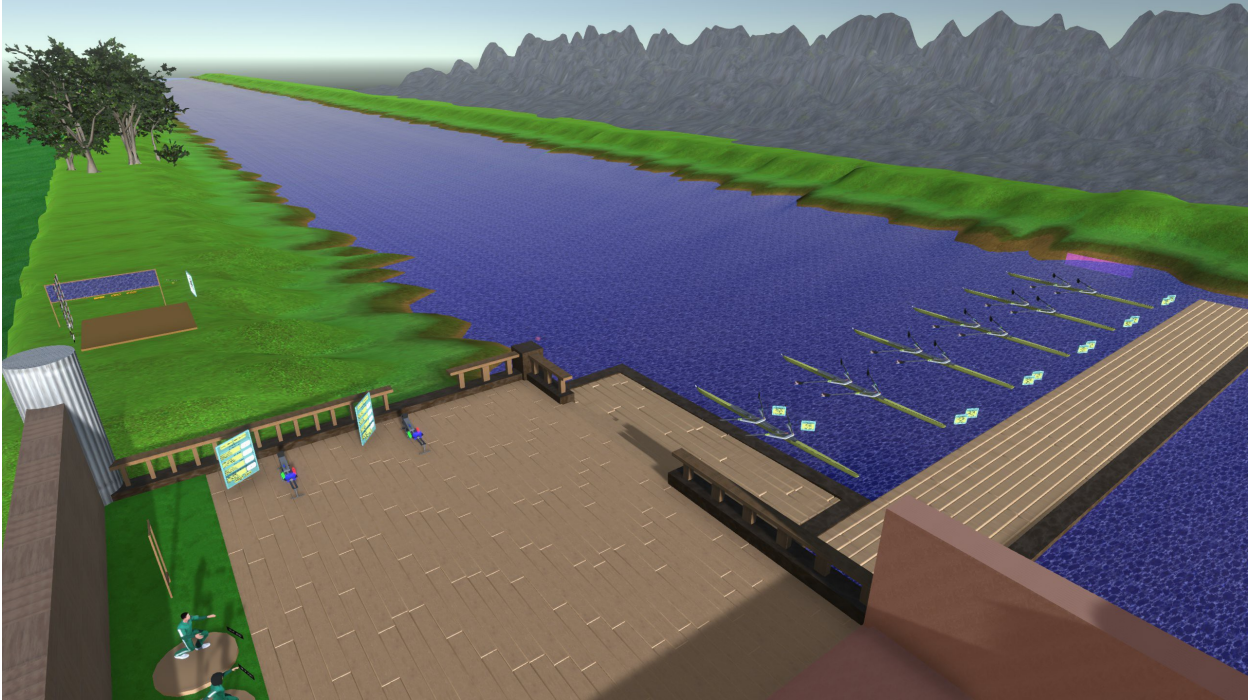


Figure 6: The dock upon completion of development.

the same as a participant are using for their virtual representation. This allows for some level of realism for the virtual character. The realism enables the avatar to be used for *technique and modelling* using *visual feedback*. For example when set at a stroke rate with a participant behind the avatar, they can train a participant to row at that rate. Lastly, Animated avatars provide new options in *team rowing*, as four participants are no longer necessary to fill a boat of four people.

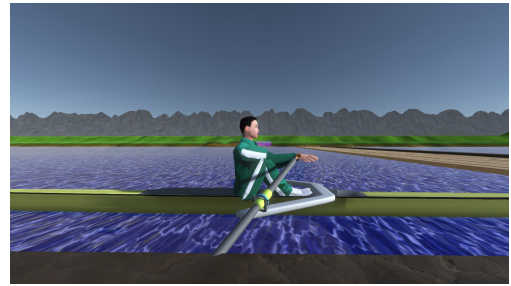
There are two types of animation, the default at a standard rate and the matching which matches another rower. The default rower animation cycles between the four stages of a rowing stroke. These are determined by four standard positions it cycles through. The four positions

can be seen in 7. The a ratio for the duration of the animation is 0.15 catch, 0.25 drive, 0.15 finish and 0.45 recovery. The ratio was chosen as per the guidance of the students working on project 1. The animation between the positions uses NeosVR's built in smooth transition feature.

For the matching animation, you can select a rower to copy the movement. Each boat and rower has a unique id for settings. When the matching id is set, the animation will automatically determine if this is a possible match. If it is, it copies the seat and oar animation of the matched rower. If the settings are wrong, the avatar will instead animate per the default animation. There is also a delay setting that can be used to replay an animation back a bit later. A



(a) Catch



(b) Start of drive



(c) Finish



(d) Start of recovery

Figure 7: Four frames of the rowing animation.

delay of one second means that the avatar performs the animation one second later than the original rower did.

In the developer room settings can be set for the animation: strokes per minute, stroke active, match boat, match rower & matching delay. The menu for this can be seen in figure 8. Strokes per minute is the only setting used for the default animation. This setting determines the time each single stroke takes. The stroke active setting activates and locks in the settings for the animation. It is used for both the default and matching animation and will lock which of the two types will be active when it is activated. The matching settings are involved in selecting and delaying the animation.

There are two main drawbacks of the current implementation: avatar's velocity contribution

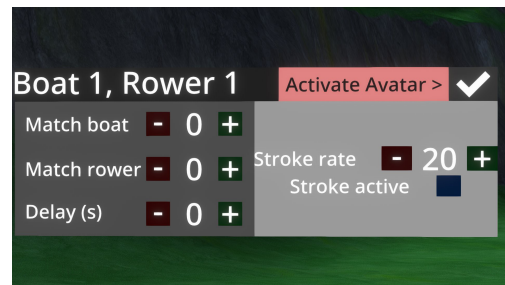


Figure 8: The rower menu when an avatar is activated.

and error copying. Firstly, the avatars do not contribute to the boat's velocity. Still, the boat's velocity is calculated as if there are multiple rowers in the boat. Thus, the boat goes slower than expected. Also, if the animation is out of phase with the human rower the boat movement will feel unrealistic as the boat will not speed up dur-

ing the drive of the avatar. The second drawback occurs when copying a human rower. In the tracking of the human rower errors can occur. This tracking is not filtered out, and thus the avatar will have the exact same tracking error if it affects the oars or the seat.

4.1.2 Extra boats

Extra boats were added to the platform mainly to add the option of *opponents*. Using the extra boats a race could be setup to create a virtual environment in which the race can feel realistic. It gives mostly the *visual feedback* to induce the feeling of a proper race. The extra boats can also be used for *self competition*, as they can be set to finish at the same point as a participant did in a previous test. Lastly, it can also be used for *pacing*. This can be done by setting the boat to a certain speed.

Using this feature up to six boats can be generated when using the wider river. In the original world, the river was too small and could only accommodate two boats. To switch between the wide and small world, the change world size button in the dev room can be used. Each boat is now generated from a template boat. Each boat can be started individually if the boat is full of human rowers. Alternatively, all boats can be started at the same time using the start training button in the dev room. A dock spanning the river has also been added to reach the new boats, as can be seen in figure 9.

Each extra boat can be designated to be an AI boat, upon which it will automatically fill with avatars. An AI boat can move independently of human input. It can do so in three ways: based on finish time/distance, based on velocity, based on difference to another boat. This can be set in the dev room menu seen in figure 10. When the

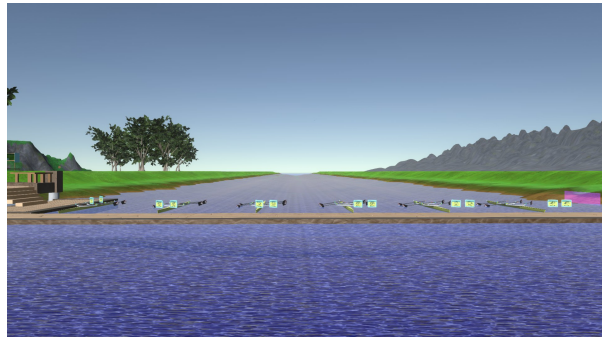


Figure 9: Wide river and expanded dock.

movement is based on time or distance, the velocity is calculated using the race settings. The time/distance setting for the AI boat is always the opposite of whether the race has been set to time or distance. If the movement is based on velocity, then the boat is set to travel at that velocity. When moving using either of these methods, the boat travels at a constant speed from start to finish as if on a conveyor belt.

When the AI boat is based on difference, it will move at the same pace as another boat. In the developer room a boat can be set to match using the boat ID. To have the AI boat move faster or slower than the matching boat a difference can be set. This difference is a percentage. The AI boat's speed is the matching boat's speed increased or decreased by that percentage. To make sure the AI boat is properly doing this, it checks if its current distance is as expected. The expected distance is calculated by multiplying the matching boat's total distance traveled by the percentage difference. It increases or decreases its speed further to get to the expected distance. An emergent benefit of this is that the difference can be manually changed to induce overtaking behaviour.

The main drawback of this system is the con-

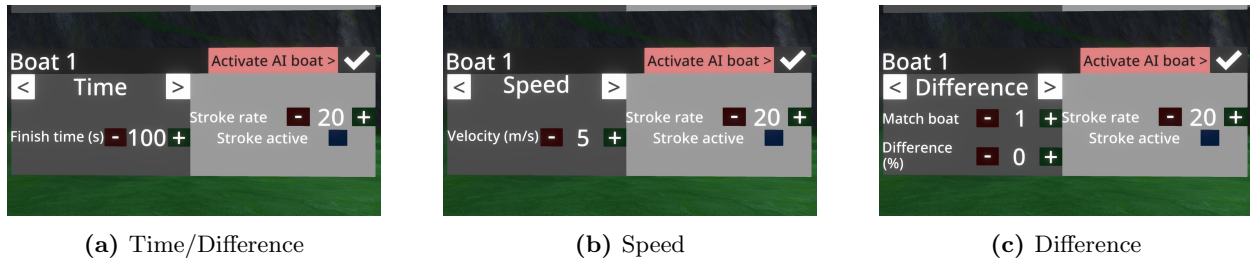


Figure 10: The AI boat menu options.

stant speed the AI boat moves at when based on time, distance or velocity. The AI boat starts by going from 0 to maximum speed in one frame. This means that the boat is far ahead of a participant’s boat if it is set to a similar average speed. This can feel disheartening to a human rower, as extreme competition works detrimental to performance.

4.2 Added platform features: usability

This section outlines features added to the platform for ease of use and developer control. These features improve the clarity of the platform and make the platform easier to get started with. This section is split into two, the developer room and quality of life. The developer room is created for more control over the system and to have a central place to input settings. The quality of life features are added to increase usability and clarity. Each section discusses why the group is important. Then introduces all the features that belong to that group. Lastly, the details of each feature are discussed.

4.2.1 Developer room

The developer room serves as a collection of the menus that only developers and researchers have

to use. In previous versions of the platform these menus were spread around the world. By having them all in the same place a researcher setting up the world does not have to move around the world as much. The added features have introduced more menus and made a bigger world. It also serves as a way to split the setup for a rower, from that of the researcher. It gives removes menu clutter from participants and reduces the time consumption for setup.

The visual depiction of the developer (dev) room is less of a room, but more a platform with menus on each side serving as walls. This is due to the nature of the expanding menus and to allow a researcher to easily enter and exit it. It is placed in a location away from the river as to not drag too much attention to it for participants. In the small world it is behind a ledge, in the wide world it is on top of the ledge.

The remainder of this section discusses the menus in the dev room wall by wall. The walls have been organised such that the menus on it are important for one another. Interfaces have been spread out over different walls to allow a researcher to be able to get close to the menu and increase the size of the menus. The following menus are present in the dev room:

- Boat generation
- Boat menu
- Rower menu
- Template toggle
- World size toggle
- Start training button
- Stop training button
- Velocity multiplier
- Training menu

On the left side of the development room, the boat generation, boat menus and rower menus are collected, as can be seen in figure 11. These menus have been put together, as they control everything related to the boats and the rowers.

The boat generation menu allows for a user to set the boat count and generate that amount of boats. Each boat by default has two rowers. For each boat a boat menu is added to the list.

The boat menus allows for activation of AI boats. if an AI boat is activated the menu displays the movement settings for the boat. If it is not that part of the menu can be used to change the amount of rowers in the boat. Always present is the option to change the strokes per minute (spm) and activate the animation of all avatars in the boat.

The rower menus are next to the boat menus. There is a rower menu for each rower in the boat. The first menu next to the boat is the stroke rower of the boat, with ID 1. Each extra rower menu is added to the right with increasing IDs. This menu displays nothing in default state.

When a human rower claims the seat associated with this menu, it displays that rower's information. It will show the websocket status on the right and the participant's data on the left. Currently it only shows the linear velocity of the flywheel and the stroke rate. The data displayed can only be edited within the code. When an avatar is activated for that seat it instead shows the matching options on the left, and the stroke rate for the default animation on the right. on the right it also has the stroke active checkbox to start the animation for that avatar.

The far side of the dev room has the template toggle, world size toggle, start training button and stop training button. This can be seen in figure 12. These buttons have been paired together because they are simple buttons that allow space for the portal. This portal will be discussed in the next section.

The template toggle allows for a developer to change the template boat, rower, boat menu and rower menu from which all others are generated. It disables all other boats, and shows the template boat. It does not disable the menus, but does show the template menu.

The world size toggle allows the researcher to toggle between the small and large world size. This button will also automatically move the dev room and dock to fit the new river size.

The start training button starts the delay countdown for all boats and begins the training. The stop training button stops all boats and immediately resets them to the dock.

The right side of the dev room contains two interfaces: the velocity multiplier and the training menu. These can be seen in figure 13. These are paired together as they influence the training settings and what happens during training not involved with individual boats and rowers.

The velocity multiplier menu allows the re-

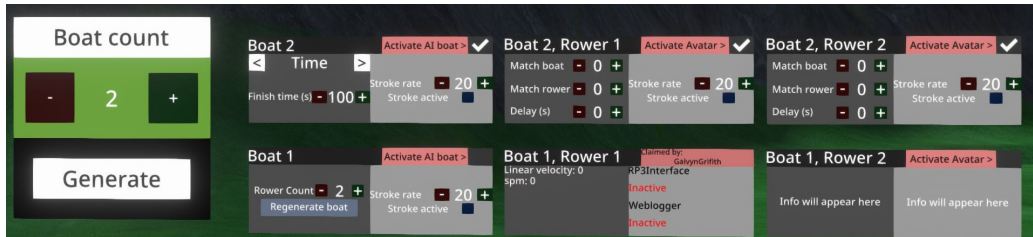


Figure 11: The interfaces present on the left side: boat generation, boat menu and rower menu.

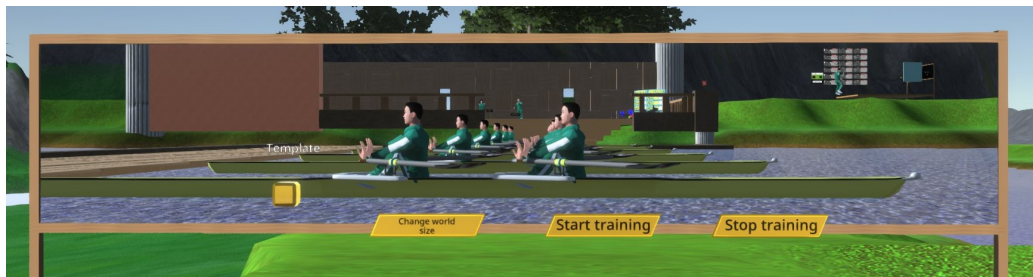


Figure 12: The interfaces present on the far side: template toggle, world size toggle, start training button, stop training button and the portal.

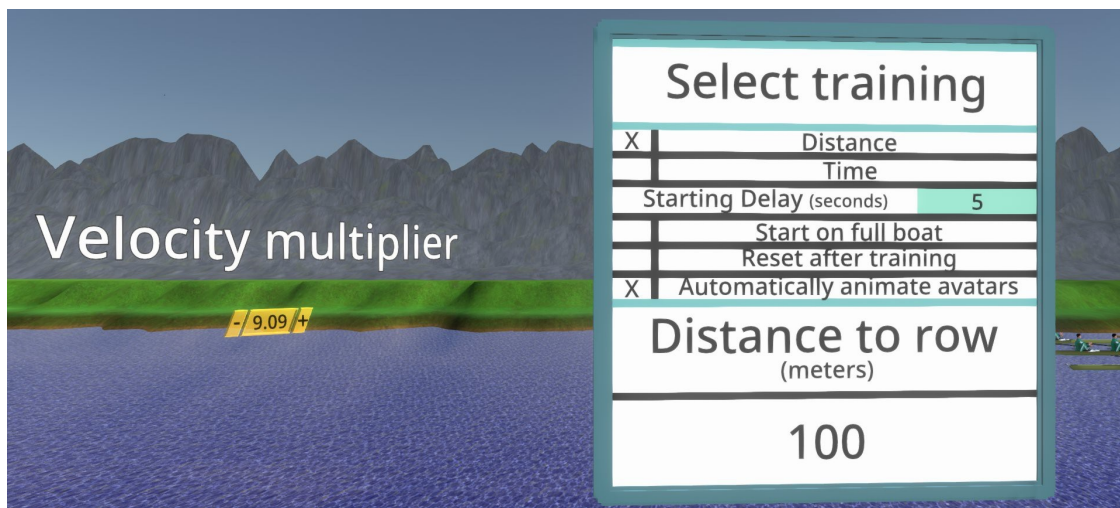


Figure 13: The interfaces present on the right side: velocity multiplier and training menu

searcher to change the multiplier. The velocity multiplier influences the calculation of the speed of the boats. By increasing or decreasing it, a researcher can change the boat velocity of their specific setup to be more realistic.

The training menu is used to set the options surrounding the training. The training can be set to distance or time. then the distance in metres or the time in seconds can be set. a starting delay can be set which is the delay between the start training button and the boats being able to move forwards.

There are three additional settings that a researcher can set. Firstly, a researcher can indicate if a boat starts the training when it is filled with human rowers. Secondly, they can indicate if the boat has to automatically reset after training has been completed. Lastly, they can indicate if the avatars should be automatically animated when a training is started, and stopped when the training is over.

The close wall and most of the left wall has been left open. These are the walls aimed towards the dock and towards the river. This has been done to easily be able to walk onto and out of the dev room.

4.2.2 Quality of life

Quality of life features are used to make the platform easy to use. It does so by increasing clarity, reducing the learning curve and reducing time taken to set up for a test. Most of the quality of life features are added for researchers. Some might also improve the experience of a participant/rower. For each feature, this section discusses the implementation and why it has been included. The quality of life features consist of the following items:



Figure 14: A mirror placed on the dock

- Mirror
- Portal
- Simplified controls
- Clear setting text
- User guide

The mirror stands on the dock, next to the avatar equipment section. It has been included for two main reasons, settings checking and immersion. A researcher can use it to check if the avatar has been properly equipped while in VR. It also allows for participants to be able to see themselves. Which helps in achieving a better feeling of control over your character.[Willaert et al., 2020] A frame has been made around it so it has a more natural appearance. It can be seen in figure 14.

As mentioned in section 4.2.1, a portal was added to the platform. This portal allows a researcher to see the boats from the developer

room. It does so by connecting a screen to a camera. The screen is in the developer room with a similar frame to the mirror, as was seen in 12. The camera is visualised as a purple rectangle and is placed on the opposite side of the river from the dock. It has been placed such that you can see all boats in the river. It has been added such that the researcher can easily check their settings without leaving the dev room.

Simplified controls have been added in favor of NeosVR's build in controls. Normally a radial user interface is used to enter the seat of the boat. A button similar to the other buttons in the menu has been added to be able to enter the seat instead. To make the buttons easier to press the menus next to the boats have been moved to be closer to the dock rather than closer to the boat. Lastly, + and - buttons have been added to change settings that require a numerical value as input. It still retains the option to type in the number. These simplified controls have been added to increase clarity of what buttons do and circumvent controls that may be difficult.

Some setting text was changed for clarity during the development process. The AI boat was previously named headless boat, which means boat without a user, because AI seemed to make its functionality clearer. Additionally the settings in the training menu are more descriptive on what exactly they influence. This was not used in other menus as only the training menu's layout allowed for longer descriptions. New descriptions were used because the computer science jargon turned out to be confusing for the students working on the projects.

Lastly, to improve the learning experience, a user guide is made. The user guide has information on components and step by step guides for certain procedures. The user guide that is used for evaluation can be found in appendix E.

Because the platform will move from NeosVR to Resonite after this thesis, the user guide has not been created in full. Some chapters would contain NeosVR specific user interfaces, but would not be used within user testing. Thus, those chapters are not completed. The user guide is added to the features of the platform with the aim to allow researchers to set up the platform without any expert help.

4.3 System architecture

To give an overview of how the rowing related features connect, a system architecture is shown in figure 15. In this figure connected systems are shown. Highlighted in pink is the original system where the boat could only be occupied by participants. Highlighted in green are the added research opportunity features. The added features build upon each other, but are not connected unlike the original system. Each boat and each rower is an individual block, not connected to any of the same type unless they are made to match them. Each rower has their own PC and is trough that connected to the VR headset, tracking and RP3 rowing machine.

Around the rowing system, the developer room blocks are added. The blocks are spaced out similarly to their location in the virtual world around the developer platform. They are connected with the settings blocks that are floating between the developer room and the rowing system. Parts of the settings are stored in the developer room and others are stored in the rowing system. The system depends on if they were developed before or after the existence of the developer room. The start and stop button are connected with all boats.

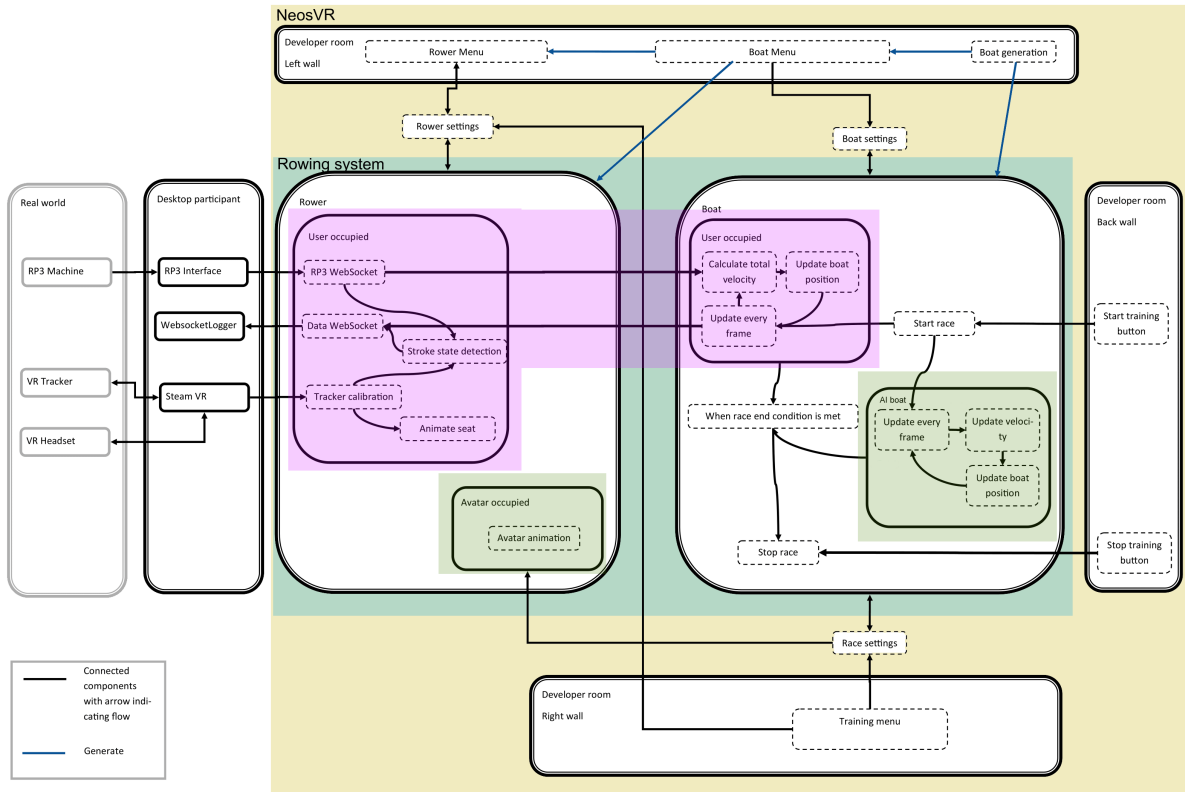


Figure 15: The system architecture around the rowing system.

4.4 Future features

During development the next features were already identified at the time that it stopped for evaluative testing. These features are: data control, adaptive AI boat velocity and realistic avatar animation. The first requires restructuring of the data storage in the system. The other two are improvements on the existing AI boat and avatar rower features. The features were not yet implemented due to time constraints and adding further menu clutter. With optimisations they can be included in a future iteration of the

platform.

Data control aims to make the data that the platform collects more readily available. Which grants more control to the researcher over in and output data. In the VR world this would take form by data being visualised in the rower menu. It also allows choosing the data to be exported, which would add or expand a menu. This menu is then connected to the data websocket of each rower. The RP3Interface and WebSocketLogger will also need to be expanded to fit this new data structuring. If preferred they could also take on

the visualisation rather than the VR world.

Adaptive AI boat velocity improves upon the conveyor belt movement the boat currently has. This feature would allow for overtaking behaviour and pacing by adapting AI velocity on other boats. This requires complex code for the boat. If implemented it allows a researcher to input a scheme to row at as well as to set an autonomous overtaking behaviour.

A realistic avatar animation focuses on making the body movements of the avatar as close to the real world movement as possible. The current movement is solely based on four positions of the seat and oars. It dynamically moves the avatar using inverse kinematics between these position. More realism can be included by adding back movement. As this is part of proper rowing technique. Additionally, the researcher can get more control by adding a setting to change the animation speed and the distribution between the phases.

5 Evaluation

To test the functionality of the platform summative user experience (UX) research is performed. UX research can give insight in shortcomings of a system and problems users encounter when trying to perform a task. This tests the system for usability. Additionally, the research was expanded to also interview participants about possibilities. This can give insight in what they think the platform might be used for, or what they would like to research with the platform themselves.

For the evaluative study two main questions were set up:

RQ1: Can a scientist of a relevant field use the platform to perform research with it?

RQ2: Does a scientist of a relevant field see future research opportunities in the platform?

These questions serve as yes or no question on if the platform can be used by someone else. Which shows if the platform is ready for use.

5.1 Method

This section outlines the method employed for the research. The study takes place in four stages: familiarisation, initial interview, user task and Final survey & interview. Each stages will be discussed in detail in this section.

Of these stages, the interview section is voice recorded and notes are made. The user task is of such nature that recording is difficult, as such just notes are taken by the researcher during the task. Before the research activity begins, participants are asked to sign a consent form for participation. This can be found in appendix D.

5.1.1 Familiarisation with the platform

During this first stage of the research, a participant is asked to familiarise themselves with the platform. The participant reads the first page of the user guide to gain a first impression. The participant is also thought the controls to move in the platform, and is asked to walk from the dock to the developer room. This allows them to explore the platform with a goal in mind. Nevertheless, they are free to walk around. During this stage the participant is also allowed to ask questions on any details they would like to know.

5.1.2 Interview on first impressions

During this stage the first impressions are discussed with the participant. This stage attempts to determine the initial expectations of the platform and gives an idea of what a researcher expects to be possible. The interview questions can be found in appendix C.

5.1.3 User task

During this stage the participant sets up two possible research setups for rowing research. They get information on what is necessary to create this research setup. During each setup the participant is asked to create a setup according to the description. During this time they are asked to use the think aloud protocol.[Baxter et al., 2015] This has the participants talk about what they are doing and what they are expecting during the performance of the task. This stage of the study aims to answer if researchers are able to perform research in the platform, as well as identify any struggles that might need to be addressed in future iterations of the platform.

To assist in achieving this think aloud protocol, the researcher performs part of the calibra-

tion using the protocol as an example. Due to time constraints, the researcher does all the initial set up. This is not part of the development of this thesis and thus did not need to be tested for. The calibration is also prone to failures outside of the participant's control. The calibration is completed when the trackers have been calibrated and the RP3 interface (websocket) is active for all human rowers.

The participant makes two test setups in the platform as part of the user task. The first focuses on phase rowing research similar to project 2. The second focuses on competition similar to project 3. To give an idea of what the test setup needs to look like a description is given that contains all the settings that need to be set. After completing both test setups, a participant is offered the option to row in the platform using the second test setup. The descriptions are as follows:

Test setup 1: phase rowing "To research the effects of visual feedback on rowing synchrony, you need to make a research setup with 2 boats each with 2 rowers. The bow rower seats are to be occupied by the participants. The stroke rower seat in each boat is to be filled by an avatar that matches the bow rower of the other boat in anti phase at 30 spm (1s delay). The trial will be at a time of 60 seconds."

Test Setup 2: competition "To research the effects of a simulated race competition on rowing performance, you need to make a research setup with six boats, each with one rower. A wide river is necessary to accommodate the boats. The trial will be at a distance of 500m. Boat 1 and 6 will row at a set pace of 3 m/s at 30 strokes per minute. Boat 2 and 5 will row relative to

the boats of your participants, being 1% faster at 32 strokes per minute. Boat 3 and 4 are to be occupied by the participating rowers.”

5.1.4 Survey & interview on usability and research opportunities

During this stage the participant first fills out a survey. The survey used for this is the standardised System Usability Scale (SUS) survey.[Brooke, 1995] This gives a standardised metric of the usability of the platform. It is followed by interview questions focused on usability. Lastly it is followed by asking participants to think up a research scenario they would want to use this platform for. As well as having the participants suggest a new feature and what research it might be needed for.

5.1.5 Participants

Participants to this research have to be involved in research movement science. The minimum level is to be studying for a masters degree. Participants are recruited from the faculty of human movement sciences at the VU. The recruited split is 2 MSc students, 2 PHD students, 1 Research support staff with a MSc in movement science and 2 Assistant professors. This makes for a total of seven participants.

5.2 Results

This section outlines the results of the research. It first shows the completion rate of the test setups. Secondly it shows the results of the SUS survey. Next it outlines the results of the observations and UX interview combined. This discusses the user experience along a few cases, what went well, what did not and what stood

out. Lastly it outlines the research opportunities that participants suggested using the platform for.

5.2.1 Completion rate

Within the user tasks participants were not made aware whether they had completed the task or not. The first task barely any participant completed the setup correctly. The second task had most participants complete the setup, some with one or two settings missing.

5.2.2 SUS survey

The original SUS survey was used. This survey has 10 questions with each question alternating between positive and negative. Each question is rated on a 5 point likert scale. To calculate a score from the survey, subtract one from questions 1, 3, 5, 7 and 9, and subtract the score from five for questions 2, 4, 6, 8 and 10. Then add the scores of all questions together and multiply by 2.5. This gives a score ranging from 0 to 100, that can be used as a grading system, with approximately 60 being a passing grade.

The final scores of the SUS survey resulted in a mean of 60 and a standard deviation of 22. This is below average compared to other usability tests with the SUS survey.[Vlachogianni and Tselios, 2022] The individual scores seem to correlate with the experience the participant had with gaming, higher scores having more gaming experience.

5.2.3 Observations and UX interview

In the interview participants discussed in more detail to what extent they think they could use the platform. The shared sentiment between participants was that the platform is difficult to

pick up initially. But given proper time they could master it and reuse it for different things.

The observations, think aloud protocol and UX interview identified three main cases of discussion: hidden UI, clarity and feedback on settings. These cases impact the usability of the platform and were noted by participants. The case of hidden UI discusses user interfaces that only appear after certain actions have been taken. An example of these actions is activating a checkbox revealing new settings. The case of clarity discusses if the function of menus and buttons was clear. The case of feedback on settings discusses how a researcher would get feedback on how a setting has been changed. These cases are discussed in the following paragraphs.

The case of hidden UI Participants showed to be eager to get to work with the platform. 71% of participants did not look back to the user guide when starting. Instead they started immediately trying to input settings in the dev room. Participants would do this by clicking on most things that were immediately visible to them. The boat generation menu was the easiest visible and understandable to participants. It was noted by all participants as a positive type of UI.

However, there was also hidden UI in the platform. The avatar and AI boat menu only show up after clicking the checkbox in the menu. All participants had trouble finding this checkbox. The participants clicked the text explaining the checkbox rather than the checkbox itself. Some participants would spam click the text waiting for any feedback from the platform. The unintentional hidden nature of this checkbox also had participants noting it as frustrating. It was noted in the interview by a majority of participants as difficult to use.

Further frustrating was the fact that the hidden settings were locked behind this hidden checkbox. Causing even more frustrations after participants had used all other buttons and still could not find what to do. As setting the strokes per minute for the avatar was mainly part of the hidden avatar menu, this also resulted in 86% of participants using the boat menu's settings rather than those in the rower menu. While this does work, it does not show the updated spm immediately upon activating the avatars in the rowing menu. The spm needs to be changed once more to show the correct value.

Table 1 shows a summary of behaviours observed with hidden UI. There is a behaviour on this topic that was not observed, but was noted by participants in the interview. As some stated that they would not automatically head to the developer room if not instructed to do so. This could increase the problem of hidden UI as there are still a few other menus in the world that might cause for confusion.

The case of clarity The UI that the user could access had varying clarity. Participants found the functionality of some buttons and the way setting worked difficult to understand. Some buttons impact the platform a lot, while others impact it little. The main button causing issues was the change world size button. 86% of participants struggled with the functionality of this button. However they did press it as it was part of the visible UI and were trying things out. The change world size button would swap the world between small and large and generate new boats to fit the width of the river, which erases all settings.

There are two similar buttons involved with boat generation: the generate boat button men-

Behaviour	Amount	Percentage
Editing the stroke rate in the boat menu	6	86%
Difficulty with activate avatar and AI boat checkbox	7	100%
Easily generate boats	7	100%
Using the platform without the user guide	5	71%

Table 1: Behaviours observed in the case of hidden UI

tioned in the previous case, and the regenerate boat button in the boat menu. When generating boats all previous boats and settings are deleted. This was not clear to participants as they would only realise this after they had lost their settings to clicking one of the generation buttons. These buttons are part of the visible UI so few participants ran into this issue as they are used before any settings are made. Nevertheless those that did run into the issue noted it as a frustration to the point that they might stop using the platform after losing the settings. Participants recommended putting a warning pop up to confirm after pressing the button.

The main unclear settings mentioned are the 'match boat' and 'match rower' settings. These settings allow the boat and animated avatar to copy the movement of another. The proper settings are to fill in the boat id and the rower id of the one the avatar should to match. Most participants filled in a guess into the settings for the first task and also noted as such during the task. This first guess was rarely correct. Some participants resolved the issue using the user guide, for others it remained unclear after the user guide.

Within the same menu the stroke active was also noted by 57% of participants to be unclear. They stated that they had no clue what it did and that they got no feedback from turning it off or on. This means that three out of five settings in the hidden animated avatar UI were unclear.

Thus it did not alleviate any frustrations caused by the hidden nature of the button and menu. The delay setting is not noted as little participants got that far into the setup of the first task.

The training menu on the other hand was noted to be clear by 57% of participants. They knew what to do when setting up the distance or time of a race. There is always a checkbox filled in here, so it was clear how to change between distance and time. Also, the value input could only be put in by typing. It was thus natural for participants to click the box and input a value. Participants found that the settings in this menu were clear. Some participants noted correctly that they were not needed for this setup.

The last important factor impacting clarity is the size of text. This was noted as a problem by a few participants. Text would either be too small or too far away. This made it difficult for them to read. A 3D game environment does allow them to move closer to the text. However, this does require them to be familiar to the controls. A way to change the text size was noted to be useful for the platform.

The case of feedback on settings To check if settings are correct participants were expecting feedback from the platform. Inputting a number was usually done correctly, as the visual number changes when the new setting is applied. However, the effects of those settings

could sometimes remain unclear. Participants often wanted to double check if the settings were correct. Sometimes this was easy, as with the visual change of the amount of rower and boat menus.

Participants also tried to get feedback by seeing if the platform would prevent them from taking certain actions. They intentionally put in what they presumed were impossible settings in hopes that the platform would stop them from doing so. The platform has no systems in place to do so, but instead performs a default action if erroneous settings have been put in.

Participants also moved in the virtual world to the boats to check if their settings have been applied. 57% of participant did so. In their think aloud they started going over a checklist of things they presumed that needed to be set while looking at the boats. The participants that moved between the boats and developer room noted higher experience with gaming than those who did not. The portal was also available, but none of the participants used the portal to check if settings were properly applied.

The experience with rowing also impacted what feedback participants were expecting. Those with little rowing experience noted to expect more feedback, or at least assistance in the game on how to set things up. Some expected the start training button to start a setup guide within the game. Participants in general expected more feedback than the platform gives.

5.2.4 Research opportunities interview

To explore if the platform can be used for research, participants were asked to suggest research they might use the platform for. In this section some of these suggestions are outlined. First the suggestion is described and expanded

to determine its requirements. Then the requirements are compared to the current features in the platform. It is then concluded on what if anything needs to be changed on the platform for that research to be performed. Aspects of the system architecture in section 4.3 or appendix B, are noted in this section as well.

There are a few main suggestions, which were suggested by multiple people. These are: phase rowing, group rowing, influence of opponents, recreating competition and visual feedback. There are also a few that were suggested by individual people that will be discussed in short at the end.

Phase rowing and group rowing both fall under the team rowing research opportunity. Both focus on rowing with multiple rowers, with one main difference. Phase rowing research focuses on the movement of the people within the boat. Group rowing focuses on the movement of the boat as propelled by the rowers. Each will thus be discussed separately based on their focus.

Phase rowing research requires participants to be able to experience the movement of another rower. They can then use this to match their movement to the other rower. The experience can be achieved by visual, auditory and haptic feedback. The current platform allows mainly for visual and haptic feedback. Visual feedback is inherent to VR, because a rower is able to see another rower. The visual feedback can also be manipulated by the animated avatar settings. Additionally, the rowing machines have an option for haptic feedback by physically connecting the rowing machines.

Project 2 in section 3.2.2 is phase rowing research and was completed with little technical support. This research needed to add a wall, such that participants were not able to see each other and only the copying avatar. So while they

could not use the platform as is, a simple change that does not impact the system can create phase rowing research opportunities. Thus, phase rowing research is possible in the platform with the current settings available. Requiring some set up from the researcher which does not involve changing the system architecture.

Group rowing focuses mainly on the movement of the boat as an effect of the rower's movement. This requires a realistic physics model for the movement of the boat. This model should be impacted by both the human and avatar rowers. This physics model currently does not exist. Additionally, avatars do not contribute anything to the boat's movement. To contribute to the boat's speed, the avatar needs to emulate the data collected from the RP3. To implement the physics model for group rowing the velocity calculation of the user occupied boat needs to be changed for realistic movement.

Another aspect of group rowing is the rolling of the boat and the movement of the oars in the water. The current setup does not allow for any rolling nor does the bar emulate real oars. A different physical setup would be necessary before incorporating these aspects in the system. Thus, full boat movement for group rowing can not be implemented in the VR system with the physical setup.

Opponents research focuses on the effects an opponent has on a participant. Common effects are a change in performance and experiencing stress. Opponents need to be better or worse than participants as well as be able to overtake and be overtaken. In the current platform visuals for opponents are present. The opponent can be set to race slightly better or worse than the participant. It does not allow for overtaking behaviour. Settings are set at the start of the race and are not dynamically changed dur-

ing a race. It is possible to manually change the difference during the race. Adding dynamic behaviour requires a change in the AI boat velocity calculation. It also needs new settings that can control the dynamic behaviour. Thus, basic opponent research is already possible, but some changes are necessary to expand into more specific research on opponents.

Research that recreates competition focuses on the effects surrounding competition. Competition can cause stressful situations and influence how serious someone takes the rowing exercise. Virtual opponents and partners are necessary to fill up to six boats with competitors, these are present. In addition to the competitors a crowd is necessary for recreating competition. Creating a crowd is a complex system of its own, which is not currently present in the system. The crowd can be implemented as a standalone feature that does not impact the current system architecture. A crowd that reacts on events in the race is more complex and does require connection to the current system. Recreating competition is possible in the current system, though there are some features that could be implemented to expand the depth of the research.

Visual feedback research is broad and revolves around any visuals that the user sees. The virtual avatars and the crowd have been noted before as visual feedback. Other visual feedback would involve mapping data to visuals that the participant can see. The data for this is available in the system, but no standardized visual feedback has been added. Thus, a researcher would need to code the data mapping and create the visuals to do research on visual feedback.

There are three research opportunities that were only mentioned by one participant. Thus, they are covered here in short. The first research opportunity is effectiveness of ergometer rowing

compared to water rowing. A large variety of setups can be made for this in the platform without coding. The second research opportunity is racing at a different race length. This is relevant as the race at the Olympic games 2028 is shortened from 2000m to 1500m. Setting the race length is possible by changing the settings. The last research opportunity is training together at a distance. NeosVR allows for people from all around the world to row together in the virtual world. Thus, this is possible as well.

5.3 Discussion on evaluation

This section aims to answer the questions posed within the evaluation. The first question, if a researcher can perform research with the platform, can partially be answered by completion rate. Completion rate shows if it was possible for a researcher to set up the platform. The first setup had a low completion rate, the second had a high one. The completion rate on the first task can be attributed to rowing experience. The first task contained rowing specific jargon, thus it was difficult to complete for participants with little experience. The second research setup did not suffer from the same jargon problem. Thus, going by the high completion rate on the second setup, a researcher is able to set up the research.

Another criteria for the first question is how easy it is to set up the research. Participants found the platform to still have a large learning curve, but all thought they could use the platform with the information provided. The observations and think aloud revealed some problems in setup, but nothing that could not be overcome with the help of the user guide. It also achieved a passing grade on the SUS scale. So researchers would be able to perform research, but the time spend to learn the platform could still be signif-

icantly reduced.

For the second question, whether researchers can see research opportunities in the platform, most researchers did see some future opportunities in the platform. They discussed a variety of research setups that might be possible within the platform. Most of the research setups are already possible in the current version of the platform. So the opportunities they see are indeed already in the platform. Some do still require some programming and system restructuring. So researchers see more opportunities than are currently available and also suggested new features. Most of these features can be implemented in the future and allow a larger future for the platform.

The questions posed in this evaluation functioned mostly as a proof of concept. A yes or no whether the platform can be used. In the next section the questions posed in the introduction are discussed. Those questions focus more on how a platform should be made. It uses results from this section that have not yet been discussed in this subsection.

6 Discussion

The evaluation shows that the platform can be used by researchers and that it has opportunities. There are still the outstanding questions from the start of this thesis. Q1: What features make for a usable VR rowing research platform? Q2: What contributes to the research opportunities of a VR rowing research platform?

As discussed in the related work, a usable research platform is classified as platform with many features that can be used by someone other than the developer. At first this thesis classified the features as research opportunities. Research opportunities are necessary for a platform to be used. However in a VR platform they should be the guideline of development and not the main focus. A VR platform benefits more from game design and user interface design.

In the formative validation projects each student got an explanation on how to use the platform and the features specifically implemented for their research. These features were proof of concept and not yet generalised. Without explanation from others that have used the platform it would have been difficult to learn these features. There was no user guide for new features at this time and the platform gave little to no feedback on what buttons did. This shows the importance of feedback on actions within the world similar to tutorials in games. As more researchers need to use the platform without any expert assistance.

The summative evaluation shows the need for UI design, to increase clarity. Some buttons were difficult to find. Other buttons were difficult to understand. UI design principles on buttons can improve how to find the buttons. For example by introducing borders and depth to the buttons. The buttons already change colors when hovered and clicked in the current platform, but if you

did not hover over it this was not visible. UI design can also assist in making the buttons easier to understand. Buttons can be better placed in the context of what they do. This can be by placing them in the location of things they change. They could get audio queues from the direction of where the change happens. Or even show a physical connection to where it changes things.

Additionally, from summative evaluation, the need for a tutorial for the setup was also reconfirmed. As the main issue participants noted was being unable to find where they needed to go. Rather than the existence of a button, this focuses on guiding the user to the location with the buttons. Also showing for a first time user menu by menu what they need to do. within game design a tutorial is often included to give a user a smoother first experience with the important options. Which in the summative evaluation was noted as frustrating that there was little clarity.

So to answer question 1: research opportunities are important features for a VR rowing research platform. As they are the basics that draw in possible users. However to make a usable platform game design and UI design features need to be employed. As employing standards from them will help with user retention and create a more positive experience.

Research opportunities were added to the platform in the form of animated avatars and extra boats. These features had a group of research opportunities they aim to achieve. The animated avatar focuses on the partners, opponents, technique, team rowing and visual feedback opportunities. It has been used as visual feedback in the first two projects to train technique. Both projects used different settings for their research. Including more options for settings, thus proved important. The animated avatars are also going to be used as opponents for project 3, as well

as a project currently in development. As partners and for team rowing they can be used as discussed in the summative validation. Though they lack the realism to be properly used for group rowing.

The extra boats focuses on the opponents, self-competition, partners, pacing and visual feedback research opportunities. They are used for partners and opponents to some extent in project 1 and 3. However, because project 3 is not yet completed the extra boats have not fully been tested on their ability to be opponents. But a new project does aim to also use them for it. For self-competition, visual feedback and pacing there are no plans yet, but it is possible in a basic version. More settings need to be added to truly explore if they can be used for these opportunities.

Project 2 did show that the extra boats can also provide additional uses outside of the research opportunities it was designed for. They used the extra boat rather to enhance the capabilities of the visual and technique feedback from the animated avatars, Showing that these new features can be used to enhance one another.

Summative validation has shown that many research opportunities can be achieved with changing of settings. While other may require some code. The main missing feature that would contribute to more research opportunities is the realism of the physics. This can be included in a future iteration.

Question 2 asked what contributed to the research opportunities. The features identified have contributed to it mostly because they have successfully targeted a large group of research opportunities. Being able to combine the different features further adds to the opportunities the platform has.

This study was not without its limitations.

The questions posed in this paper were quite broad. During development the focus switched from research opportunities, to usability of the platform. So while the formative validation originally mainly focused on the research opportunities. The summative validation focused more on usability. A more extensive formative validation with the projects could have ensured that usability issues were encountered earlier. The current development focused on providing support when needed. A more proactive formative validation in which the students would participate in user experience research such as diary studies and interviews might have provided more insight earlier.

7 Conclusion

This thesis has provided work on the rowing reimagined platform that is a shared effort between the two universities. It aimed to make a VR rowing research platform by expanding upon the existing platform. New features were implemented that focused on adding research opportunities and improving usability. It is validated by formative and summative evaluation. Which shows that other researchers can use the platform.

There is still room for improvement in the current platform that can expand the opportunities even further. It has also uncovered questions on how to incorporate gaming and UI design research. This research can be used to further improve the usability of the platform. Future features have been suggested, such as realism and improving the extra boat for opponent behaviour. This however will have to wait until after the platform has been transferred to a new game called Resonite, which improves on the concept of NeosVR.

After the transfer, future work can be done to add new designs and research opportunities. Until then researchers are already able to use the platform as is. In appendix A steps can be found to download and explore the platform. And in appendix E the completed sections of the user guide are provided.

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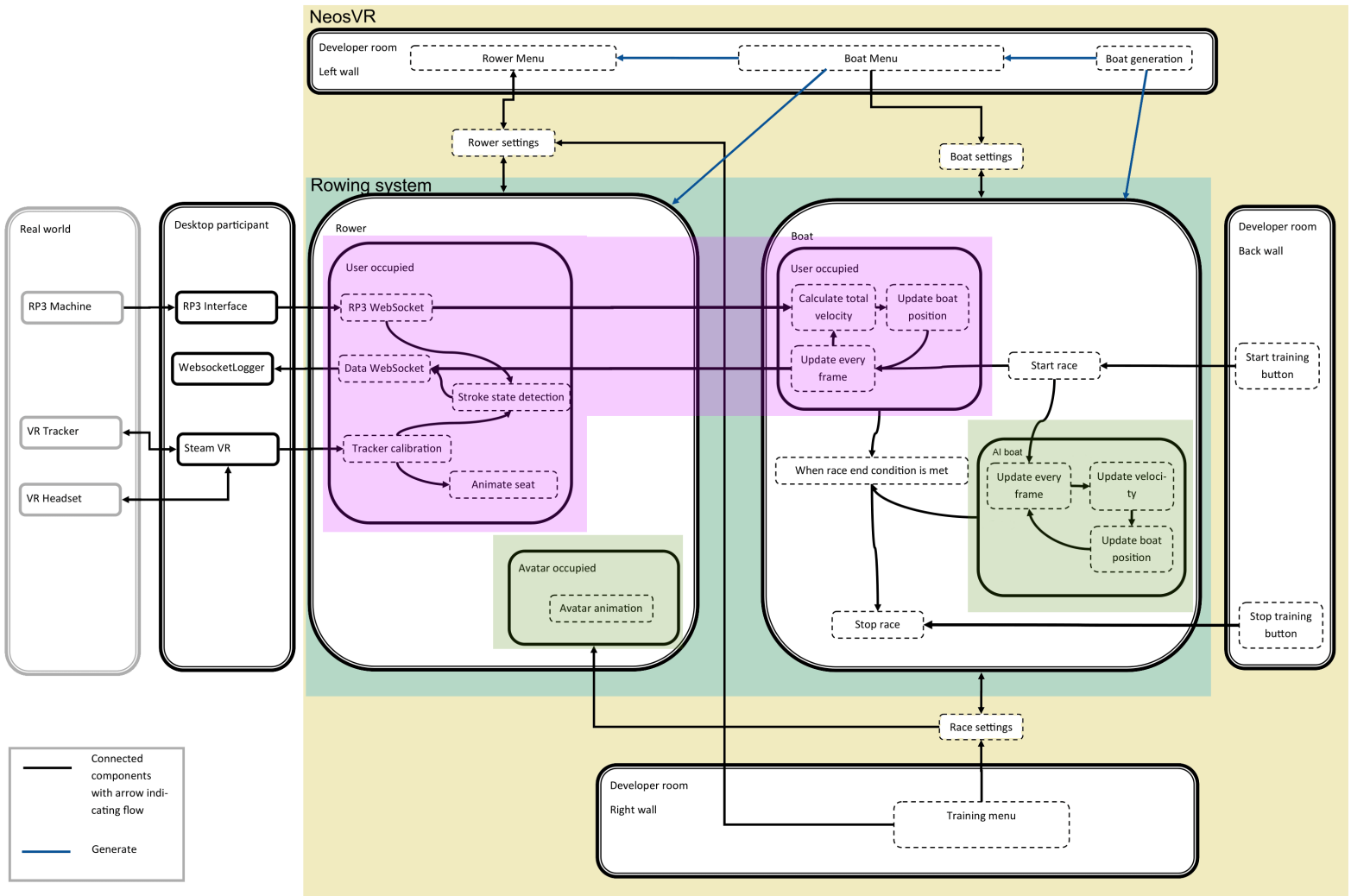
Appendices

A Instructions to open the NeosVR platform

To gain access to the platform, you will first need to download NeosVR. this can be done trough steam, which is the company that also adds the VR capabilities to the platform.

Once the game is installed, open this link in a browser: <http://cloudx.azurewebsites.net/open/world/G-UT-Mixed-Reality/R-93a36f7c-eb9c-4cc9-b044-25d2f5945548> The browser will then ask to open the NeosVR launcher. Which will automatically open the world upon opening.

B System architecture



C Interview questions

C.1 General information (before user task)

1. What level of research are you in?
2. What is your field of research?
3. How many years have you been at this level?
4. what is your (study) background?
5. Do you have any technical experience?
6. Have you worked with technology based research platforms before?
7. Do you have any experience with rowing?

C.2 First impression questions (before user task)

1. Would you be interested in this platform from the first page of the user guide?
2. On a first glance does a type of research within your field come to mind that this platform might be used for?
3. Does the user guide give you an idea of what you will need to do to use the platform?
4. Do you have any expectations for how the platform works?

C.3 Concluding questions (after user task)

1. How would you describe your overall experience?
2. What did you like the most?
3. What did you like the least?
4. After having created the test setups, has your view on the possibilities of the platform changed?
5. Did something about the platform surprise you?
6. Did anything in the platform cause frustrations?
7. What was the hardest part of setting up the platform for research?
8. What was the easiest part?
9. If you were to do research with this platform can you suggest research setups you would make?
10. If you were able to suggest features what features would you need, and what research would you like/need them for?

D Rowing reimaged consent form

ROWING REIMAGINED

THE DESIGN, DEVELOPMENT AND EVALUATION OF A MULTI-PERSON MIXED REALITY ROWING PLATFORM

INFORMATION BROCHURE

The Rowing Reimagined project is a large-scale research project that focusses on the design, development, and evaluation of a multi-person, mixed reality, rowing platform. The project is carried out by a multidisciplinary team of researchers, working on different studies. You are reading this information brochure because you are asked to participate in one of these studies. This information brochure provides you with general information about the Rowing Reimagined project. More detailed information about this study will be provided orally by the researcher(s) involved. Feel free to ask any questions. Your participation in this research is voluntary and you are free to withdraw from participation at any time.

What is the purpose of this research?

The aim of the Rowing Reimagined project is to explore the potential of virtual reality (VR) for rowing. Can VR help rowers to *perform better*, *learn faster*, or train in a *more engaging way*? These are some of the questions that we set out to answer. Besides these rowing-specific questions, we are also focusing on the design of the system itself. How can we design the interaction between athlete and machine in a meaningful and effective manner?

What will participation entail?

To explore the potential of VR for rowing, you may be asked to participate in various research activities. Research activities include, but are not limited to:

1. Rowing in Virtual Reality. Many of the studies related to the Rowing Reimagined project involve rowing in VR. For this kind of research activity, you will be placed on a rowing ergometer (RP3) and you will be equipped with VR equipment (VR headset and trackers). The movements that you make on the ergometer will be translated to rowing movements in the virtual world. During the experiment, you may be presented with different experimental conditions. For example, to study 'social connectedness', we may ask you to row *with* and *without* an avatar present in your virtual boat.
2. Qualitative research methods. Many of the studies related to the Rowing Reimagined project involve the collection of *qualitative* data. These methods may be used to better understand rowing practice, but may also be used to study usability, user experience, or subjective experiences of rowing in VR. Qualitative research methods include: interviews, observations, surveys, diary studies, self-reports, and other qualitative data collection methods.
3. Quantitative research methods. Many of the studies related to the Rowing Reimagined project involve the collection of *quantitative* data. These methods may be used to better understand the biomechanics, biodynamics, and physiology of rowing. Quantitative research methods include: recording movement data through motion capture, computer vision, and VR trackers; recording physiological data through heartrate sensors and respiration sensors.

Are there any risks of adverse effects?

Virtual Reality is known to induce motion sickness in some people. Motion sickness arises when there is a perceptual mismatch between what we *see* and what we *feel* – as might be the case in a car or on a boat. We have designed our system to minimize the risk of getting motion sick. If, however, you feel nauseous, light-headed, dizzy, or generally unwell, alert the researcher immediately to halt the research. If you are aware that you are sensitive to motion sickness or have had bad experiences with Virtual Reality in the past, you may not participate in research activities that require you to enter virtual reality.

In rare cases, Virtual Reality might also induce a photosensitive epileptic attack in people who are sensitive to light and bright flashes. If you are aware of such sensitivity, you may *not* participate in research activities that require you to enter virtual reality. The researchers will always closely monitor your general well-being. The researcher may halt the experiment when there are signs that you are not feeling well.

May I withdraw from the research?

You may withdraw from the research at any time. You do not need to justify your decision to withdraw. If you wish to stop the experiment, simply notify the researcher. If you have concerns after completion of the experiment, you may ask for your data to be removed. This should be done within 24 hours of the experiment.

What will happen to the collected data?

The studies that are carried out in the context of the Rowing Reimagine project will involve the collection, use, and storage of research data. The data may be qualitative or quantitative in nature.

To protect your privacy, we will make sure to anonymize all data. In some cases, anonymization, however, might not be possible, as might be the case with video or audio data. We will only record video or audio data when necessary. If possible, we will blur out your face and make your voice unrecognizable so that none of the data can be traced back to you. To further protect your privacy, your data will be labeled – if applicable, any links to personally identifiable information will be removed. The researcher will indicate on the ‘informed consent form’ whether personally identifiable information will be collected in your case. Personally identifiable information will never be made public, any data that is used in scientific publications cannot be traced back to you. Anonymized data however, might be made part of a publicly available corpus.

The data from the Rowing Reimagined project will be safely stored. Data will be stored for 10 years on a GDPR-secure location, according to the GDPR guidelines. You may ask for your data to be removed within 24 hours upon completion of the experiment.

Will I be reimbursed for participation?

If not indicated otherwise, there will be no (monetary) compensation for your participation in this research.

What can I do if I have questions or complaints?

If you wish to seek independent advice or file a complaint, you can contact the secretary of the ethics committee of the University of Twente (ethicscommittee-cis@utwente.nl). For any additional questions regarding this research, please contact dr. D.B.W. Postma (d.b.w.postma@utwente.nl) or any of the other researchers involved in this research project.

What is next?

With this information brochure, you have been informed about the general scope of the Rowing Reimagined project. Next, the researcher that is involved in the current study will provide you with additional information on the specifics of their study. If you have been fully informed about the purpose of the research, the research procedure, and the relevant research methodology, both in writing and orally, you can sign the informed consent form.

INFORMED CONSENT

I hereby declare that I am fully informed about the purpose of the research, the research procedure, and the relevant research methodology. I have read and I understand the provided information and have had the opportunity to ask questions.

To the researcher: ~~strikethrough which option is not applicable.~~

I give my consent for the collection of: anonymous / personally identifiable information data, the kind of which has been detailed in writing (in the information brochure) and orally.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost.

Date:

Name:

Signature:

.....

E User guide

0 Rowing Reimagined User Guide

Rowing Reimagined User Guide

Welcome to the rowing reimagined user guide. This document will guide you through all you need to know about setting up the rowing reimagined platform.



Introduction

Rowing reimagined is a research platform designed for easy access to VR in rowing research. It allows you to have participants row on an ergometer, but give them a VR environment to make it appear more similar to on water experiences than regular ergometer research. Current features include:

- Single, double and quad scull rowing
- Online rowing
- Animated rowers
- Up to 6 AI opponent boats
- Extensive data collection
- 2 river widths
- Researcher room for with settings

Quick links

- [1 First time setup](#)

- 2 Physical setup
- 3 RP3 Interface and data collection
- 4 Entering and storing the world
- 5 (Rower) Setup
- 6 (Researcher) Using the developer room

Step by step guides

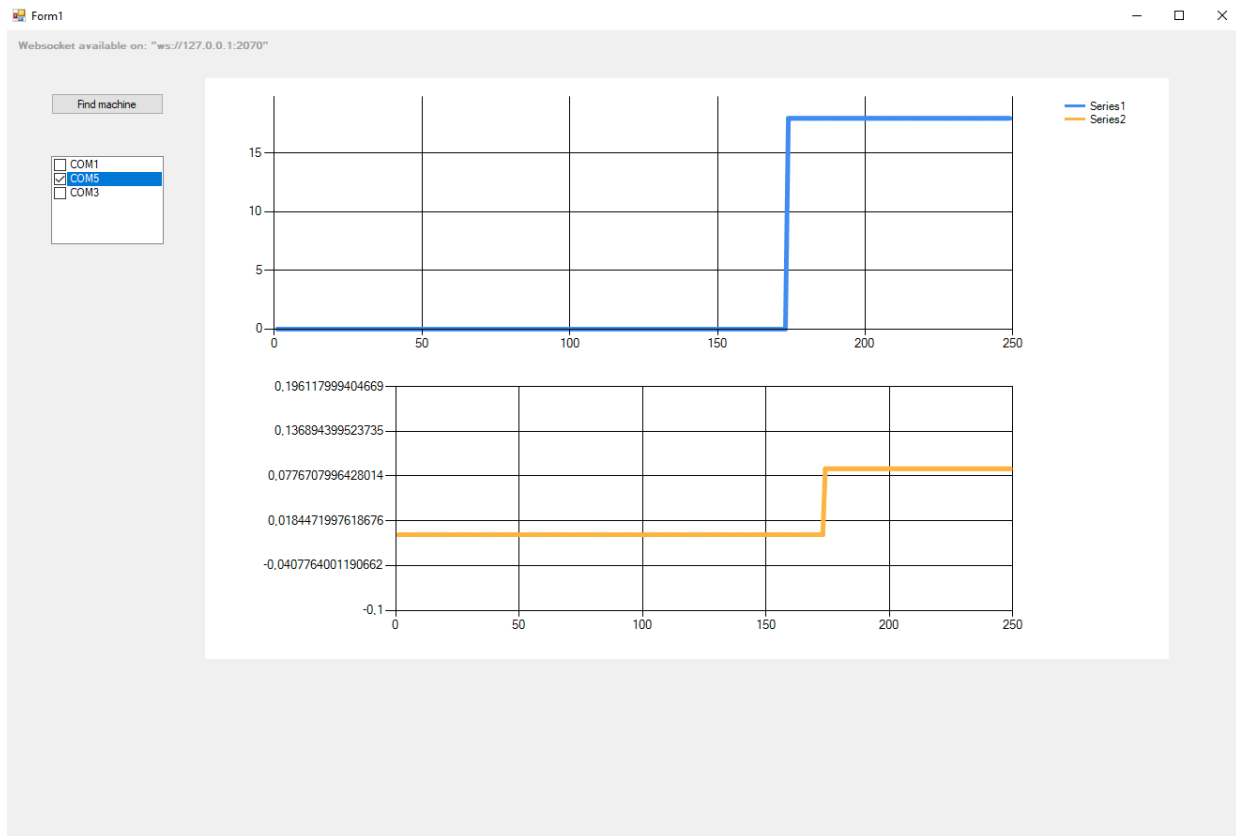
Setup for an individual test in NeosVR

1. Enter the neosvr world on the researcher computer
2. Choose the [World Size](#)
3. Invite and enter the neosvr world with the rower computers
4. Turn on the RP3 interface and data collection websocket for each participant as in [3 RP3 Interface and data collection](#)
5. Perform rower setup up to [Entering the boat](#)
6. Set up the training by choosing from the options in [|Training menu](#)
7. Generate the amount of boats you need using [Generate Boats](#)
8. Set up Boat Size using the [|Boat Menu](#)
9. Designate any AI/non-participant boats in the same menu
10. Claim the seat with the participant rowers as in [Entering the boat](#)
11. Set up the other rower seats with Avatars as needed in the [|Rower menu](#)
12. Have participants enter the boat
13. Make sure the data collection websocket is running as in [|Data collection websocket](#)
14. Press the start training button to start the race
15. After the race is completed the boats will automatically stop
16. Press the stop training button to reset all boats

3 RP3 Interface and data collection

RP3 Interface

Download the RP3 interface from <https://github.com/marsmaantje/RP3-Interface/releases/tag/20230317a>. Once you have unzipped the file, you can boot up the program by double clicking the RP3 interface.exe application.



After clicking the Find machine button, a list of COM names should appear in the menu on the left hand side. These are all the detected USB devices. Select the one the RP3 machine's usb is connected to. Usually this is the one with the highest number. If you've selected the right port, the graph will spike up. If you've not selected the right port, close the program and start it up again. Then choose a different port. Once you have the right port you can leave this program running in the background.

Data collection websocket

Download the datacollection websocket from <https://github.com/marsmaantje/WebsocketLogger/releases/tag/2022.10.18b>. Once you have unzipped the file, you can boot up the program by double clicking the RP3 interface.exe application.

Form1

C:\Users\Jordi\Desktop\Vogs\newLog.txt

Open file

Auto add newline Append data to file

Last message

Cache size

0 Autosave Cache size
-1 for no limit

Save File

Stop

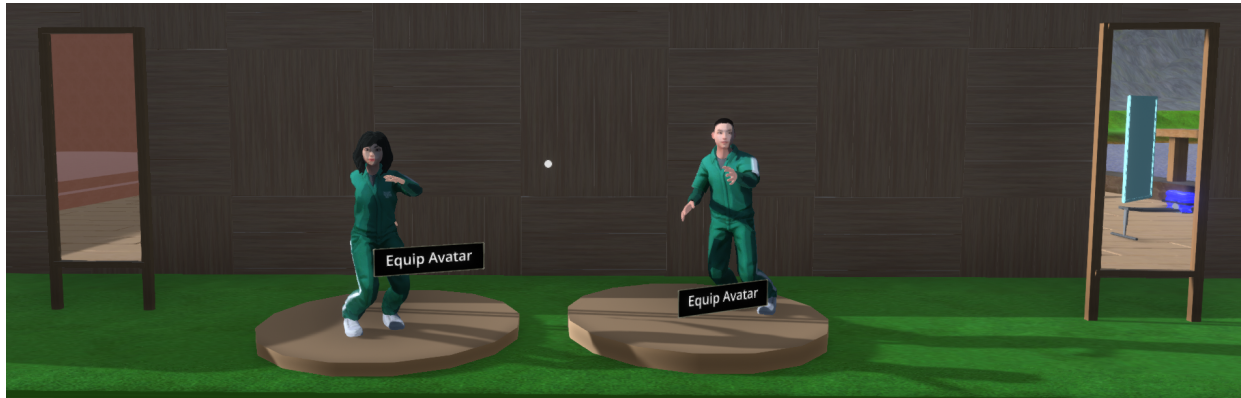
Running

In this application first click open file to navigate to the location where you want to save your file and give it a name. Afterwards press the start button at the bottom of the application to start collecting data. Preferably do this just before a training/race is started. Once you have collected the data press stop to stop collecting data.

To collect new data, select a new file new. Then press start again.

5 (Rower) Setup

Equipping an avatar



Using the black equip avatar button, you can equip the avatar of your choice. Make sure to click the equip avatar button and not the statue itself. As grabbing the statue will disable the button. You can use the mirrors on either side to check if it has equipped correctly

Aligning the virtual machine

Main menu

Tracker Selection Adjust alignment

Tracker Selection

MachineTracker

Select tracker

Remove tracker

Highlight tracker

null

SeatTracker

Select tracker

Remove tracker

Highlight tracker

null

HandleTracker

Select tracker

Remove tracker

Highlight tracker

null

BackTracker (Optional)

Select tracker

Remove tracker

Highlight tracker

null

Align Save



In this main menu you can select all physical trackers. Simply click select tracker, and a red cone tool appears in your hand. point this cone towards the tracker that is to be selected and click once again. It should now show the tracker id in the right part of the menu.

You can remove the tracker by clicking the remove tracker button. And highlight a tracker by clicking the highlight tracker button. You can use this to check if the right tracker is selected.

After selecting all necessary trackers, click align and save. Then make sure you are seated on the RP3 rowing machine in real life before moving on to adjust alignment.

Adjust alignment



When seated on the physical machine enter the RP3 replica in VR by clicking on the seat and selecting enter seat in the pop-up menu by moving your arm up and clicking. You can now adjust the orientation and location of the virtual machine, such that it lines up with the physical machine. Use the different adjustable values for this

Adjust angle

If the machine seems to be rotated, use adjust angle to rotate it until it is parallel to the physical machine.

Forward/backward machine offset

Use this value to move the flywheel section forwards and backwards.

Left/right machine offset

Use this section to shift the flywheel section left and right.

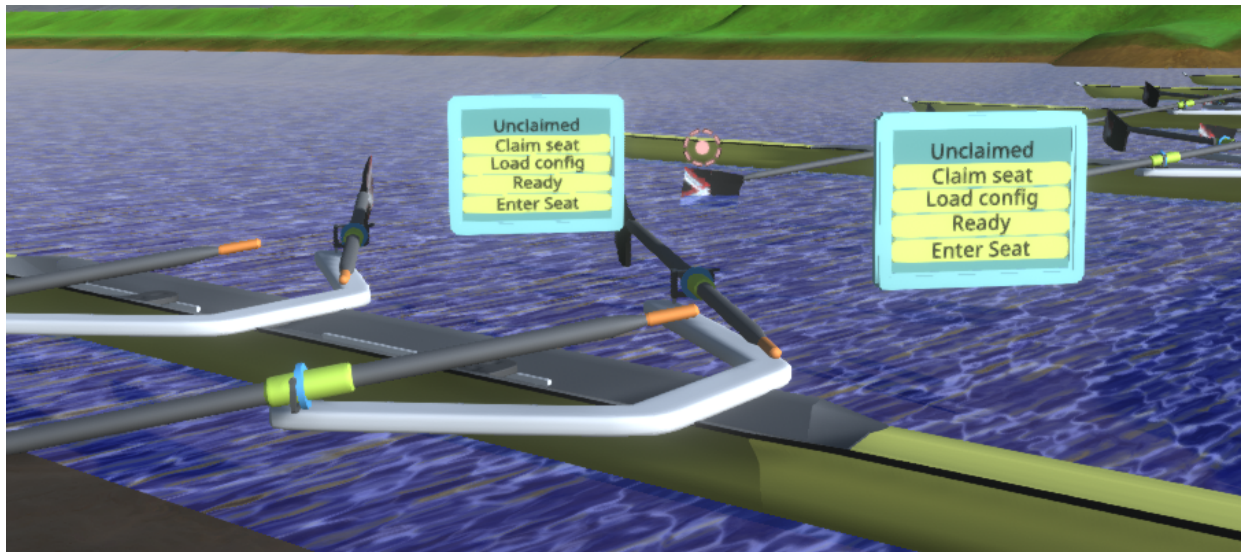
Up/down machine offset

Use this to shift the flywheel section up and down.

Forward/Backward seat offset

Use this to shift the seat forwards and backwards.

Entering the boat



Entering the boat is as simple as pressing all four buttons after each other. Going in order from top to bottom. Once someone has entered the seat and the **RP3 Interface** is active, they are ready to row. They will be allowed to row when the start training button is pressed in the developer room. Or once the boat is full and that setting is active in the training menu.

6 (Researcher) Using the developer room

Description of segments

World Size



The leftmost button under the camera feed in the developer room allows you to change the world size. The small world has space for 2 boats, the large world has space for 6 boats. The button can be used to toggle between world sizes. For the other buttons refer to [Starting a training](#). For the portal refer to [Portal and leftover settings](#).

Training menu

Select training

<input checked="" type="checkbox"/>	Distance
<input type="checkbox"/>	Time
Starting Delay (seconds)	5
<input type="checkbox"/>	Start on full boat
<input type="checkbox"/>	Reset after training
<input checked="" type="checkbox"/>	Automatically animate avatars

Distance to row
(meters)

100

Training type

The first two options allow you to set the goal of the training at either distance or time.

General settings

Starting delay

This sets the time delay for the boat to start after the start button is pressed.

Start on full boat

This will allow a boat to start the race when it is fully filled with human rowers. This only starts the boat that is filled up.

Reset after training

This allows the boat to automatically reset after it has completed the training.

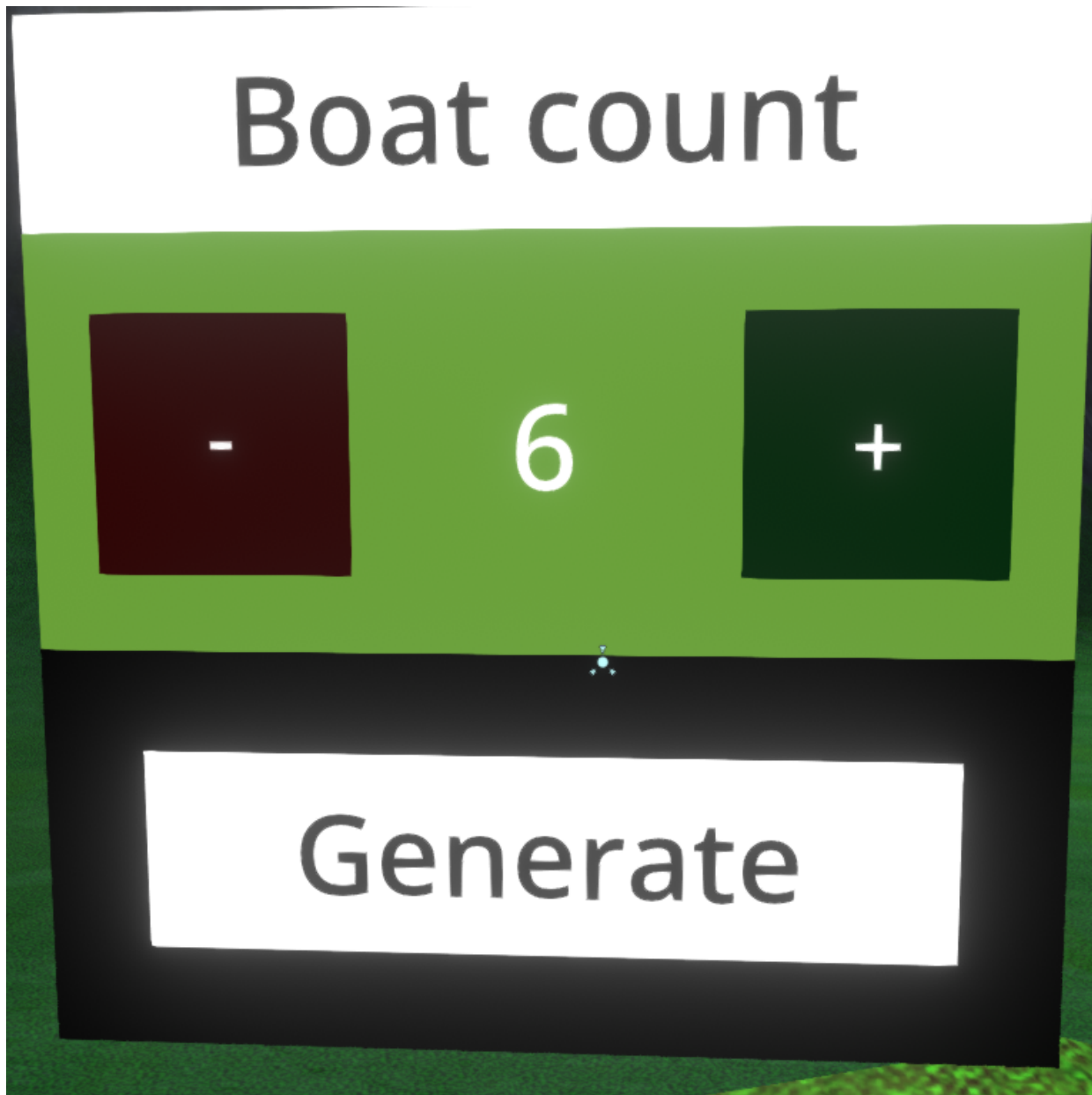
Automatically animate avatars

This settings starts the rowing animation automatically upon the start of the training and disables it after completion.

Setting a distance/duration

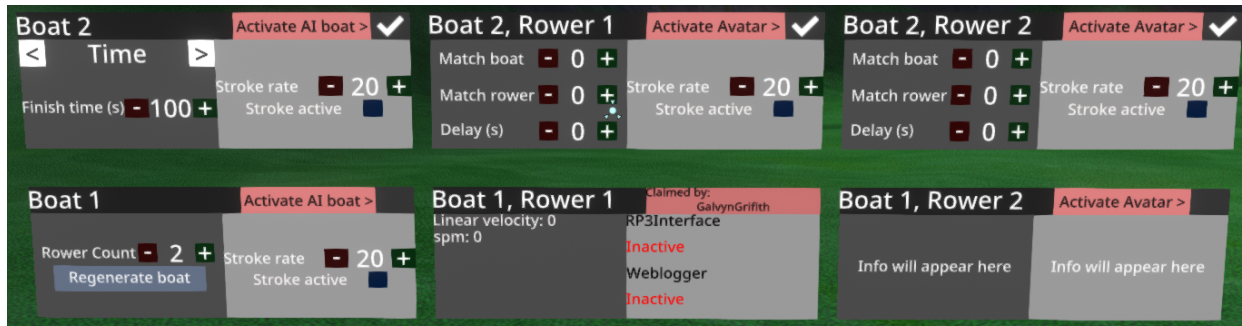
In this menu you can fill in either the distance of the training or the time that you will be rowing for.

Generate boats



In this menu fill in the amount of boats that are necessary and then click generate. The small river will automatically generate 2, the large river will automatically generate 6. Each boat contains 2 seats.

Boat & rower menu



The boat menu serves as a way to set up opponents and partners. After having generated the amount of boats you need, you can edit their properties here.

Boat menu

The boat menu are the leftmost interfaces

Participant/non-AI boat (Boat 1)

In the Boat 1 menu on the left bottom the basic screen can be seen. In this menu you are able to change the amount of rowers in the boat using rower count. Once you have the amount of rowers you want to have, click regenerate boat.

The stroke rate and stroke active menu is always present for boats. This controls the stroke rate of any avatars that have been activated in the boat. Any stroke animation attributes will only be applied each time the stroke is activated. If you have changed stroke settings for any avatar, restart the stroke.

AI/non-participant boat (Boat 2)

Once the checkmark in the top right is clicked, the AI boat will be activated. This boat is automatically filled with avatars. There will now also be a menu on the left side to determine the speed of the boat. This can be done by three metrics: Difference, speed and time. Determined by the top bar.

Difference

When choosing difference you can fill in which boat ID to match. The boat ID can be found in the top left of the menu. You can also fill in the difference as a percentage. If you were to fill in 1% difference to a boat going 10km/h, the boat will travel at 10.1km/h.

Speed

In this menu you can directly fill in a speed for the boat to travel at. This speed is in metres per second (m/s).

Time/Distance

This menu changes based on the training type, refer to [Training menu](#). You can fill in the distance in metres or the finish time in seconds. The boat will then automatically calculate its speed based on the training length.

Rower menu

The rower menus are the interfaces after the first one on the left. Rower 1 is the stroke rower.

Basic rower (Boat 1 Rower 2)

When the seat the menu is connected to nor has a participant claimed the seat the menu will appear like this. The only thing displayed will be "Info will appear here"

Participant rower (Boat 1 Rower 1)

Once a participant (or researcher for participant) has claimed a seat (refer to [Entering the boat](#))

, the menu will display some values related to the rower on the left. On the right the activity status of the RP3 interface and data WebSocket is displayed. These should both be green when the training is started.

Avatar rower (Boat 2 Rower 1 & 2)

When the checkbox is marked on the avatar rower, an avatar will appear in the seat. This avatar can be animated to row at a certain pace. To animate it at a certain pace use the right side of the menu to set a strokerate and to activate the animation.

To animate it based on another rower use the match function. At match boat fill in the boat ID of the rower you want to match. At match rower fill in the Rower ID that you want to match. For example match boat 1, match rower 1 will have the avatar row in the same tempo as the first (stroke) rower of boat 1.

To delay the animation you can fill in a value in seconds in the delay field. This means the avatar will delay the movement for that long.

Starting a training



Start training

Start training will send the command to all boats to go and start rowing after the delay set in the **starting delay**.

Stop training

This will stop the training. Instantly returning all boats to the starting position. Use this to get boats back to the dock.

Portal and leftover setting

Portal



The portal allows for easy viewing of the docked boats.

Velocity multiplier



Change the value in the velocity multiplier to change the calculated speed of the boat. A higher multiplier means a higher calculated speed.