Measuring Eye Movements in a GTA V Cycling Simulation

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***Abstract*—A common limitation of many current vehicle simulators is their lack of realism/fidelity. Improvements in the level of fidelity are accompanied by large investments. A low-cost alternative would be to use the environment of Rockstar Games Grand Theft Auto V (GTA V). The level of fidelity of the GTA V environment is high, and, the game is modifiable, yielding the possibility to create a simulation scenario in GTA V- in the form of a mod. The purpose of this study is to demonstrate the feasibility of researching cycling behavior in a GTA V driving simulator.**

We created a simulated scenario consisting of 12 traffic situations which are controlled by triggers. When a participant enters a trigger a piece of code is executed. In this way, actions of other vehicles were controlled, as well as traffic lights.

Furthermore, an eye tracker is employed. The eye tracker information is sent to GTA V, which transforms it into game coordinates. This allows for real-time measurement of what the participant is looking at in GTA V.

Next, we demonstrate that it is possible to record and create figures of the driven path, the horizontal gaze, and looking at areas of interest (AOI).

Our main finding is that modifying GTA V is a relatively fast and easy way to make a driving simulator to collect data for different research purposes.

We conclude that our code and mods may allow future researchers to create their own driving simulation scenarios in GTA V and combine the real time data logging of an eye tracker with the GTA V data logs.

***Index Terms*—Driving simulator, bicycle simulator, hazard detection, GTA V, Grand Theft Auto 5.**

I. Introduction

ANY foreign tourist visiting the Netherlands will probably be amazed by the incredibly large number of cyclists, especially in Amsterdam. According to a study conducted by the European Commission, 36% of the Dutch people use their bicycle daily [1]. Therefore, it is relevant to do more research on the behavior of cyclists in traffic. A common way to do this is to use a simulator to examine the behavior of cyclists. Up until now, most of the driving simulator research has been focused on cars, whereas cycling simulator research has been scarce. This makes it interesting to do more research on cycling simulators.

In the past, a great amount of money has been invested in creating driving simulators. Usually, these simulators fail in achieving an adequate level of virtual reality. Especially the graphics are disappointing. In a previous study [2], participants were asked for their opinion about the reality of a driving simulator. The average score was between 4 and 6 on a scale of 1 to 10. This in contrast to the game industry, where highly realistic virtual environments have already been created. Therefore, it seems logical to make use of these realistic environments, when creating a driving simulator. The great potential of using games for research has not gone unnoticed by other researchers. For example, OpenAI has created OpenAI Universe [3], in which games are used as a simulated environment for machine learning. The Berkeley Deep Drive [4] autonomous driving model has already been implemented in OpenAI Universe successfully [5]. It appears to be feasible to create a driving simulator in a gaming environment.

A suitable game for creating a driving simulator should be modifiable and it should have a realistic environment. We used GTA V [6], which is arguably one of the most realistic games created up until today. Moreover, GTA V is known to be modifiable. The GTA V community itself has already created a large variety of mods [7].

Eye tracking allows researchers to study the simulated environment. Additionally, eye tracking makes it possible to measure cognitive load and perform research on people's behavior in traffic [8].

The goal of this paper is to demonstrate the feasibility of researching cycling behavior in a GTA V driving simulator. This is done in combination with an eye tracking system.

The participants undergo a scenario filled with several common traffic situations, relevant to cyclists. The possibility of creating a high and low fidelity scenario is investigated. The events in the scenario are triggered by the actions of the participant. The eye tracker data is combined with GTA V, so real time measurements can be done of what the participant is looking at in-game, also known as gaze coordinates.

Several measurements are performed, a few of them are recorded in this study. The real time measurements of gaze coordinates are used to derive a gaze pattern of each participant during the entire scenario. Furthermore, the cycle path, gaze variability and gaze distance among two curves are plotted over a top down view graphic.

The NASA-TLX survey is used to measure frustration levels of participants. The participants are divided into a low and a high frustrated group. These two groups are compared to each other based on the amount of time they look at Areas of Interest (AOI) in certain events. Two groups, with and without a driver's license, are compared to each other in the same way.

The driven path at one specific event is researched. As a participant cycles past a parked car, the car door opens unexpectedly. The reaction of the participants is recorded by measuring the driven path and the cycling speed along this path.

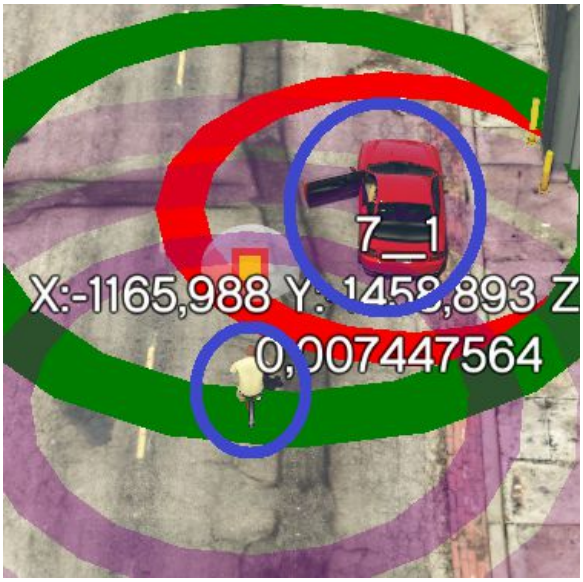

Fig. 1. Situation 1: car door opens. A driver suddenly opens his door without looking, when the cyclist drives past. Immediate reaction is required.

Fig. 2. Situation 2: motorcycle from the opposite direction. The cyclist wants to turn left, but a motorcycle drives past from the opposite direction.

II. Design

A. Scenario design

Participants cycle along a scenario, with the help of voice controlled instructions. This scenario consists of a number of traffic situations, which are relevant to cyclists. These mostly include ordinary situations, like intersections, but also special situations, like the unexpected opening of a car door. In the second case, a quick reaction of the participant will be necessary, in order to avoid a crash. In other cases, the participant won't have to take immediate action, but is likely to attend to the event that takes place.

For creating the scenario, the original urban environment of GTA V was used. Consequently, a route had to be found in GTA V, that is, suitable for cyclists. The goal was to find a route, with small streets and small intersections, either with or without traffic lights. Due to the flexibility of the large GTA V environment, finding such a route was not a problem. Table 1 shows two situations of the scenario. The entire scenario is included in the appendix A and videos of the scenario are uploaded on YouTube [9] [10] [11] [12].

The scenario works in the following way. We remove all computer generated traffic from the game. All traffic included in the scenario, is programmed into the game by us. The main ingredients of the traffic situations are triggers and actors. Triggers are circles with a variable radius and actors include all vehicles in-game. All events in the scenario are controlled by triggers. When the participant enters a trigger, a piece of code is executed. An actor is then instructed by a piece of code to perform a specific action. For example, a car can be instructed to start driving when the participant approaches it. Traffic lights are also controlled by triggers.

In figure 1 and 2 two situations of the scenario are shown. The participant and the relevant actors are marked with a blue circle. The red and green circles are triggers. A trigger is normally red, but turns green when entered by the participant.

B. Implementation

GTA V can be modified using Script Hook V [13] in C++, .NET (C#, F#, Visual Basic) [14] and Lua [15]. Due to the safe nature of the language and amount of code examples available we decided to use C# using Community Script Hook V .NET, a .NET wrapper for Script Hook V. Script Hook V is implemented using a detour [16] for DirectX (dinput8.dll) to read and modify GTA V.

The mod is programmed in the "tick" function of GTA V. This function is called each frame in the main GTA V thread and only in this thread can the game be read and modified. This limitation increases the complexity of multithreading due to synchronization issues, especially during network communication. The full code is added in appendix B and in Github [17].

C. Eye tracking

1) Eye tracker hardware: For this project we use the SmartEye DR120, it is a remote 3D eye tracker with a 24" wide HD screen with a Dark Pupil and iris/corneal reflection head model. It has an accuracy of 0.5 degrees head rotation and 0.5 degrees gaze. The eye tracking sampling rate is 120 Hz. The advantage of the DR120 is that it is more comparable to conventional simulators as the conventional simulators also use a screen or multiple screens instead of virtual reality type gear.

2) What to measure: Within the scope of this project, the primary interests are scanning patterns, that is where does the participant look, and how is his/her looking behavior distributed. These results can be processed together with a data log of participants and the controlled traffic location in GTA V as a function of time.

3) Eye tracking coding: To use information from the eye tracker in GTA V we use the UDP logging protocol as specified by the vendor. We are interested in what the participant

Fig. 3. UMTRI simulator [20] (conventional simulator)

is looking at on the screen and in the world. To achieve this we use the world intersection feature of the eye tracker. The coordinates received by the eye tracker correspond to the screen size used, the coordinates are then normalized to fall within (-1,1) for the x and y coordinates.

The received coordinates have a certain degree of noise, which complicates detection of what a participant is looking at. To smooth the signal we have implemented a weighted moving average algorithm which resets on saccadic eye movement.

$$
\begin{aligned}
\varepsilon &= \text{saccadic distance threshold} \\
\bar{u} &= \text{gaze coordinates} \\
w &= \{w_1, w_2, \ldots, w_n\} \\
v &= \begin{cases} \{\bar{u}\}, & \|\bar{u} - \bar{v}_n\| > \varepsilon \\ \{\bar{v}_2, \ldots, \frac{\sum_i^{n-1} \bar{v}_i w_i}{\sum_i^n w_i} \bar{u}\}, & \text{otherwise} \end{cases}
\end{aligned}
$$

To convert the screen coordinates to world coordinates we use the camera transformation matrix, which we read from GTA V memory using signature scanning [18]. This transformation matrix is then applied in reverse to the screen coordinates to retrieve the direction vector the participant is gazing at. Using this vector we ray cast [19] from the camera in the direction of the gaze to retrieve if the participant is looking at an actor.

4) Data Logging: We log relevant data from the eye tracker for processing after the experiment. We log the following data from GTA V: position, heading, speed and time. We also log the frame number from the eye tracker to synchronize the data afterwards.

D. High and Low fidelity

First this project was meant to be a research project. We wanted to compare the cognitive workload while using GTA V in high fidelity versus low fidelity. GTA V in low fidelity can be seen as a conventional simulation. This chapter shows what has been done regarding downgrading the fidelity. To downgrade the level of fidelity in GTA V, the fidelity level of conventional simulators (figure 3) has to be compared with that of GTA V (figure 4 & 5).

Fig. 4. GTA V with high fidelity

Fig. 5. GTA V with low fidelity

GTA V (figure 4) has a lot more detail and texture than a conventional simulator (figure 3). A large render distance and loads of random objects like trash cans are also well known properties of GTA V. To delete/decrease these components, changes in the GTA V code have been made. The Level Of Detail (LOD) has been reduced, so it loads a 3D model with lesser detail. A shader has been used to make the textures simpler. The render distance is lowered and random objects are deleted. The result is shown in figure 5, which was made in an external program called CodeWalker. This is how the GTA V simulation in low fidelity should look like. In appendix D there are different ways described that were tried to lower the fidelity of GTA V. Unfortunately a low fidelity version of GTA V turned out to be more challenging to achieve within the given timeframe.

III. Methods

1) Before the Experiment: Before the experiment started, the participants were asked to fill out a consent form (appendix C.1) and two surveys to control for variance between the test subjects. The first survey contained general questions like gender (78% male) and age (22±1.93), but also questions like what their gaming experience is and what kind of dangerous situations they've experienced while cycling. 85% of the participants gaming experience and 59% have any gaming experience with GTA V.

The second survey contained questions about how they feel in the present moment, for example whether they were bored or motivated before doing the experiment.

After filling out both surveys, the eye tracker was calibrated to the participant and he/she was asked to do the task.

2) During the Experiment: The participants were told to ride the bicycle as they normally would in real life and to obey all the traffic rules. They received an instruction form, for all the information needed to do the task (appendix C.2). The participant entered a scenario in GTA V where he/she had to follow a path by bicycle and meets a number of common traffic situations to which he/she had to respond. A voice in the simulator told the participant where to go. Appendix A shows pictures of the scenario.

3) After the Experiment: After finishing the scenario, the participant was asked to do the same task once more to generate more data.

When the scenario was finished for the second time, the participant was asked to fill out the rest of the survey. This third survey contains questions about how the participants felt like while doing the task. The questions were the same as the survey before the task.

In order to assess the own experience of the subject after participating in the experiment we asked them to fill out the NASA Task Load Index (NASA-TLX) questionnaire. This questionnaire rates the subjective workload of the task.

The surveys and the NASA-TLX are attached in appendix C.3 and appendix C.4 respectively.

IV. Results

Due to the combination of real time logging in GTA V and the eye tracker different measurements can be easily done. For this paper the following measurements are made to show how it can be measured and processed:

- Participants position/heading/speed
- Did participant looked at an actor?
- Actor's position when looked at
- Distance between actor and participant
- Trigger activation
- Pre and post experiment survey
- NASA TLX survey

With these measurements a lot of results can be generated. In this paper we made 4 types of results:

- Driven path in x-y coordinates
- Heat map
- In-game gaze variability
- Looking at AOI vs. time for different classes

The results of participant 13 are shown in this paper, all the results of other participants are presented in appendix E.

A. Driven path in X-Y coordinates

The driven path of figure 6 is the path of the whole scenario of one participant, but we can also make a driven path graph of all participants for one event. In figure 7 is shown the driven path of all participants in the opening car (red rectangle) door event.

The participants follow a clear path around the opening car door. Where the path is darker, the more participants have driven on those coordinates. The same graph can be made but then with differences in velocity of every participant as shown in figure 7.

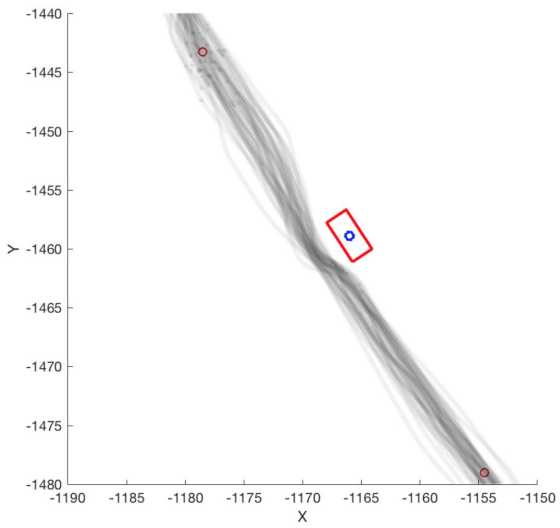

Fig. 6. Driven path in X and Y Coordinates in GTA V, opening car door

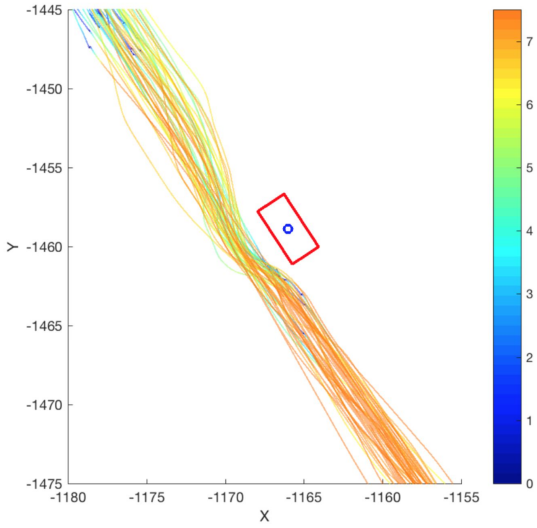

Fig. 7. Driven path in X and Y coordinates in GTA V, velocity included, opening car door

The velocity in GTA V does not have a real unit. We can only observe the velocity relative to each participant.

B. In-game gaze variability

The gaze coordinates are real time integrated in Grand Theft Auto V so you can directly see where you look (figure 8, 9 & 10). In figure 8 the participant is looking at the street, nothing happens. However when the participant looks at a car or pedestrian, the car or pedestrian will get a red circle around it (figure 9 & 10).

C. Driven path including looking behavior

Because of the integration of the eye tracker in GTA V we can make a plot of the driven path with the looking behaviour

Fig. 8. Looking at the street in GTA V

Fig. 9. Looking at a car in GTA V

of a participant. In figure 11 is shown a plot of the driven path with the gaze variability in top view.

D. Heatmap

With a gaze versus time graph it is difficult to observe a pattern. That is why a Heat scatter is useful to represent a gaze pattern as shown in figure 12.

Looking at AOI vs. time for different classes A research would not be a research if you cannot compare results of different participants, that is why there is a ”Looking at AOI vs. time graph” for highly frustrated and low frustrated participants defined in the NASA TLX survey made as shown in figure 13.

Fig. 10. Looking at a pedestrian in GTA V

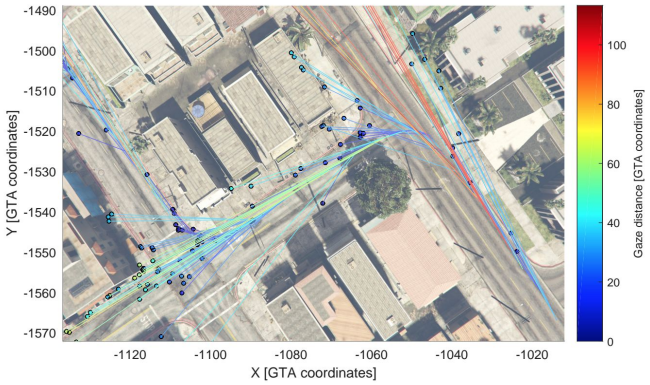

Fig. 11. Driven path including gaze variability and distance, participant 13.

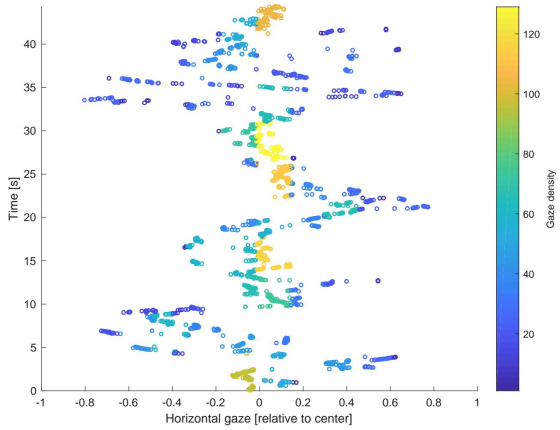

Fig. 12. Horizontal scanning heatmap of participant 13.

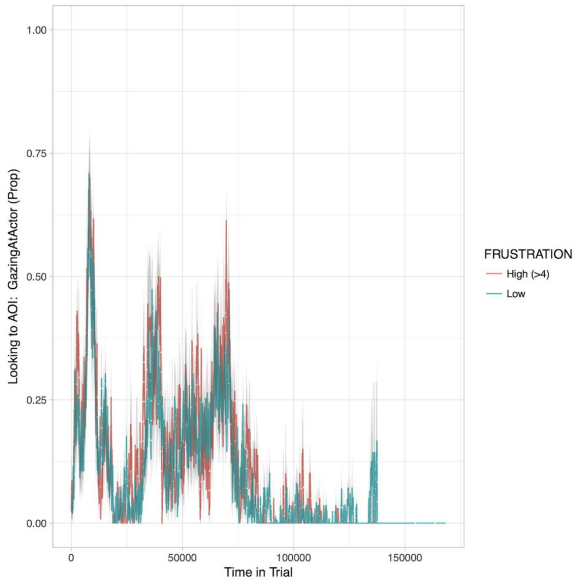

Fig. 13. Looking to AOI vs. time in [ms] for High and low frustrated participants

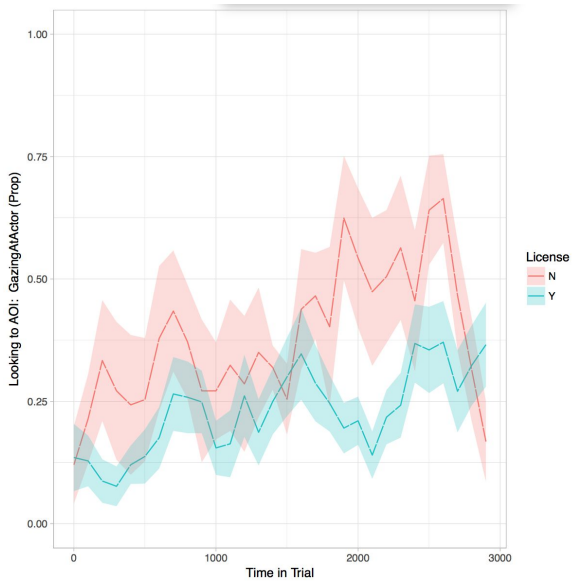

Fig. 14. Looking at AOI vs. time in ms since the trigger, opening door

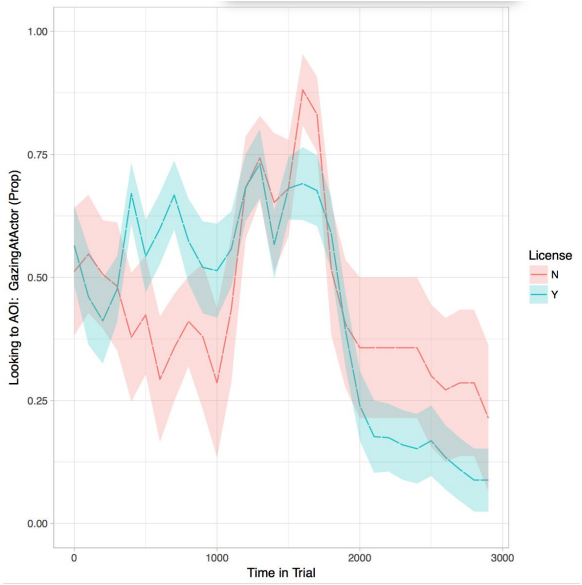

Fig. 15. Looking at AOI vs. time in ms since the trigger, car from left

The AOI are cars or pedestrians in hazardous situations and is defined as a percentage of participants who looked at these AOIs. Every 100 ms GTA V measures if a participant is looking at an AOI.

However there is an uncertainty in this graph because every participant has different experiment duration. The results of an event occurred in a scenario are time independent because of the rush of the participant. Due to measuring the time of trigger activation of an event we can set the ”time in trial” equal for every participant in a certain event. So there is a new time X-axis relative to the activation time of the trigger. We made a graph of ”Looking to AOI vs. time” for participants with and without a driver’s license for one event as shown in figure 14 and 15.

V. Discussion

Distances in GTA V are not equivalent to distances in real life. They are based on assumptions that have been made about the average size of different types of objects. This assumption is then translated into the amount of coordinates that would fit in a unit.

In order for the participants to control the bicycle in GTA V we used a game controller. The use of a GTA V simulator in combination with a real bicycle and three screens will neglect the aspect of gaming experience of the participants because there will be no controls that have to be used. This makes the cycling experience more realistic and will potentially deliver the researcher more reliable data.

In this paper some of the questions from the standardized surveys [21] have been altered to fit better to the information that we desired to collect. However, in order to compare the results from the surveys to the results of other research papers it is necessary to use the exact same questions.

It is necessary to look into the ethical objections against the use of GTA V for scientific purposes because of the violent and misogynistic content of the game.

VI. Conclusions and Recommendations

The purpose of this study was to demonstrate the feasibility of researching cycling behavior in a GTA V driving simulator. For this purpose, we have programmed a simulated cycling scenario in GTA V built in C# using Microsoft Visual Studio and used an eye tracker to run experiments with 27 participants.

Our main finding is that modifying GTA V is a relatively fast and easy way to make a driving simulator to collect data for different research purposes. Because GTA V already contains a wide set of patterns and objects, it is to be considered as a better option to make your simulation look very realistic compared to conventional simulators.

An advantage of using a GTA V driving simulator is that it offers the researcher the possibility to make the simulation interactive. It allows to introduce several events into the simulation which take place at a certain point in time or when the participant enters a trigger based on the participant’s actions. The researcher can design the trigger as desired which can be used to create a surprise effect for the participant.

Another advantage is the real time data logging of the eye tracker data combined with the GTA V data logs such as heading and speed of the participant, allowing the researcher to link the two data streams. The convenience of linking these streams is for example that it is possible to automatically log whether a participant is looking at an actor while driving through the simulated environment. The real time gaze data can be combined with the localization of the actor and will be processed automatically. This allows the researcher to transform the 2D coordinates of the eye tracker to 3D coordinates. Conventionally, this used to be done by hand by plotting the eye tracker data over a screen capture. Using this feature allows to collect data more accurately and saves time while processing the data.

Creating a scenario with GTA V is less costly and time consuming than the programming and use of a conventional simulator.

A possible research topic could be whether using a GTA V simulation combined with an eye tracker with real time logging allows to measure the mental workload of participants more accurately. The participants have a more detailed world to look at compared to a conventional simulator. In order to find out whether the results of a simulation made with GTA V will be more accurate than the results of a low fidelity GTA V simulator, a research can be done on whether a downgraded low fidelity version of GTA V shows different results than the high fidelity version. Although the low fidelity version of GTA V turned out to be more challenging to achieve within the given timeframe, it is possible to create it with the use of Open IV. It allows the scenario designer to change everything within the world of GTA V. A recommendation for a research question could be: Is there a difference in cognitive workload of the participants between a low and high fidelity simulation in GTA V?

In addition to the research described, the real time logging of the eye tracker combined with the GTA V data log gives the researcher countless possibilities to generate data on many different research topics.

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