DEPARTMENT OF INFORMATICS
Technische Universität München

Bachelor's Thesis in Informatics

VR – Perception of Time & Immersion in Situations of Acrophobia

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VR - Zeitwahrnehmung & Immersivität in Höhenangstszenarien

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I confirm that this bachelor ’s thesis is my own work and I have documented all sources and material used.

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Abstract

In this thesis the different ways of measuring time perception and effects of subjective time distortion will be discussed. The theory of an internal clock, which is influenced by certain stimuli, is one possible explanation for different time perceptions. The theory states, that when presented a certain stimulus, the perception of time is speeding up. The goal of our study is to measure the time perception of multiple participants in situations of acrophobia. This was done in a virtual environment, which has the advantage of creating scenarios in an easier and more controllable way – compared to "real life" experiments. As the experiment takes place in virtual reality, it is also possible to measure more complex data such as brain activity using electroencephalography (EEG). In our experiment we tracked time intervals, which the participants produce. The experiment consists of three main actions: Staying, Falling and Flying. The effect of those on the produced durations will be compared. Furthermore, we analyzed possible connections to the EEG-Data and especially a connection to the P3 potential. For each action the participants produced multiple durations (220 iterations in total). We measured short durations of time production when falling and flying compared to standing. The effect for falling and flying also decreased over time. Also, the participants performed a visual task, where the speed of the visual perception was tested. The results of this sub-test were unexpected and will be discussed in the following. Also, the comfort in virtual environments and the possible interaction methods (for example for traveling) will be portrayed.

Contents

Introduction

Differences in time perception are a well-known phenomenon in the field of psychology.

Those differences mean that people feel like time is elapsing slower (or faster) than it does in reality. Such a feeling can be experienced in different situations. It does not matter if the situation itself is positive or negative, but as discussed in this thesis, the situation has to be unexpected or at least cause some emotional reaction.

Our goal was to identify the differences in time perception of three different actions (or events): standing (or staying), falling and flying. Falling and flying are emotional / unexpected situations, whereas standing is representing a non-emotional situation. For each iteration of the experiment, the participants (or subjects / users) tried to produce a one second interval – once before and once while the action happened. Our participants were college students and the study took place at the Katholische Universität Eichstätt-Ingolstadt.

For the virtual experience we also tried to reduce the effect of feeling sick. This effect is called cyber sickness (in the following just sickness). The study took more than one hour per participant, so the comfort of the experience in virtual reality (VR) had to be as high as possible. This was achieved by using the methods described later in this thesis.

How to measure Time perception

Gil and Droit-Volet (2011) describe multiple ways of measuring time perception in an experiment at Clermont University in France. They had eighty-seven students who were randomly assigned a task. The mean age of the participants was about 21. For their study they isolated the subject in their laboratory and the answers were given through pressing a button on a keyboard. The study was about emotional stimuli in form of faces, for example an angry face. The goal was to examine if the subjects emotional time perception would be faster, when presented such a stimulus. They used five different temporal tasks to evaluate if the emotional stimuli have an effect on time perception.

The following methods for time measurement will be described and discussed based on the work / experiment of Gil and Droit-Volet (2011).

Temporal bisection

There are two parts of the bisection task.

The first one is the training part, where a “short” and a “long” time period are presented to the participant. They are called “anchor durations” and the durations are for example 400ms for the short and 1600ms for the long period. To do this, the subject is advised to guess the time, which passed within the period and press one of two different buttons, one representing long and the other a short period.

After the training phase the test started and a pre-determined set of durations (for example 6 different ones) which are all longer than the short, but shorter than the long anchor durations are being shown to the subject. The subject then has to start the experiment by pressing a button. Then the stimulus is shown, and the participant has to guess if the duration is closer to the long or short anchor duration. The results are recorded and analyzed.

Temporal generalization

For Temporal generalization the subject is being presented a "standard duration", which is the reference duration the participants try to reproduce. Then the participants saw some emotional stimuli and furthermore, decided whether a shown duration, which is again part of a pre-determined set, is "equal" or "unequal" to the standard duration. The test is divided into multiple blocks and the standard duration is being shown multiple times at the beginning of each trial and the task consisted of three blocks. So, the main difference to the temporal bisection is that for temporal generalization it is the participant's task to tell if it is the same. For temporal bisection the subject has to identify if the duration was shorter or longer than the previously shown standard duration.

Temporal verbal estimation

For the verbal estimation task two different durations, which are part of a pre-determined set, were shown to the participant. In the study of (Gil & Droit-Volet, 2011) they chose 200ms and 1800ms. The durations were shown multiple times in a randomized order in form of a neutral stimulus and the subject had to guess the length of the short and the long duration. Afterwards the emotional stimulus was shown multiple times and the participants had to estimate the intervals. For the guess a specified range was given, within the participant could choose a number.

Production

In the production task the participant was told a duration (for example 500ms) in form of a text on a screen. The subject was asked to produce this duration by pressing a button, once the subject assumed that the stimulus was visible for the previous defined time. Then the participants went through the same procedure again, but this time they were being presented an emotional stimulus instead of a neutral one. They again had to press a button once they assumed the desired duration was reached. The participants performed multiple trials in a random order with different emotional stimuli and durations.

Reproduction

For the reproduction the participants were shown, rather than being told a duration. After the given duration was being demonstrated the subject had to reproduce the duration. The subject could reproduce the duration by pressing a button, after a stimulus was displayed for the duration shown before. For the first five trials – which is called the training phase – the participants were presented a neutral stimulus, which should have no effect on their time perception. However, after the training phase was finished the emotional stimuli were shown to the subject. The subjects performed multiple trials for three different emotional stimuli and the pre-defined given durations.

Choice for the study

For the study the procedure should be easy to perform by the subject and should also be suitable for a VR-Scenario. We decided, that remembering different durations over a long period of time while wearing a VR-Headset and falling of a building is too much input for a study in which the subjects participate only once and not multiple times. This means that we didn’t choose Temporal bisection, temporal generalization or temporal verbal estimation since, through the additional training / presenting phase, they are more complex than the production and reproduction.

Also, significant results should not require many repetitions, because one measurement-set - which would be one guess with and one without the stimulus - includes falling, staying or flying as an action that has to happen every iteration and teleporting from a safe place to the front of the rooftop. In conclusion one measurement set would take multiple seconds and so we wanted to choose a procedure which does not require many iterations.

This approach also leads to production and reproduction, because the subjects do not compare durations with others, but instead produce a value (delta), which is not binary but can instead vary.

In the end we decided to choose production, because it is easier to tell a person a specific duration than displaying it in VR. Also, the displaying could lead to some problems in which the participants may be distracted by the fact that they are falling and not pay attention to the produced duration.

Virtual Reality

Setup

VR Headset

The VR Headset had to meet certain conditions to prevent the participants from feeling sick and aborting the experiment.

The visually indicated motion sickness (VIMS) occurs at the time when at least one of two main conditions is present. The first condition is a high input lag, which is the duration between the action of the user that is taking place and the time until this action gets visible in the Virtual Environment (VE). (Porcino, Clua, Trevisan, Vasconcelos, & Valente, 2017), (Hettinger & Riccio, 1992)

So, the first requirement for the VR Headset would be a low input lag. However, FPS are not the same as input lag, but the FPS has effects on the input lag. If for example the framerate of the simulation drops to ten, only ten frames will be displayed per second, meaning that in average there will be an input lag of 100ms. In conclusion a stable (and high) frame rate is necessary.

Also, the development should be as simple as possible, and the program has to work on a Windows 10 PC or work as a standalone headset.

We chose the Oculus-Rift, because standalone headsets are not as powerful as the ones powered by a PC, if the costs are similar. Also, we have had experience with the development on Oculus Rift and its integration in Unity3d works seamlessly.

The Oculus Rift is a VR Headset by Facebook Technologies LLC (previously Oculus VR LLC), which is connected to the PC with a USB cable. The movement tracking is done by one or multiple sensors, which are also connected through a USB cable to the PC. (Facebook Technologies LLC, 2019)

Development

For the development of the VR experience we chose the game engine Unity3d by Unity Technologies. For the development of the virtual environment and the measurements we used "Unity version: 2018.2.17f1". Unity provides a wide range of assets in the "Unity Asset Store", from where we got most of our 3D models. Also, Unity has an integrated interface to the Oculus Studio – the software necessary to use the Oculus Rift.

Comfort and immersion in Virtual Reality

One of the main goals we had for our virtual environment was that the participants do not feel sick and that they do get the feeling as if they actually were on a high building. In conclusion we tried to design our environment and the interactions in a way that works in favor of these factors.

Acceleration

Porcino et al. (2017) collected multiple factors, which make users feel discomfort in Virtual Reality and can be solved through a correct level and interaction design as well as the development of the virtual experience itself. Based on their work, fast acceleration is one of the main factors for discomfort, as it creates a conflict between the seen picture and the physically perceived motion.

This means fast velocity changes cause high discomfort, whereas slow acceleration is more comfortable for the user. In conclusion movement should begin and end slowly, rather than instantly, in order to maximize comfort. This will be discussed further in the next section, as it debates travel in virtual environments. (Porcino, Clua, Trevisan, Vasconcelos, & Valente, 2017)

Degree of control

Unexpected camera movement which is not controlled or indicated by the user also leads to a feeling of sickness. Camera movement should at best be controlled by the user's head-movement (Porcino, Clua, Trevisan, Vasconcelos, & Valente, 2017) or at least anticipated by another object to prepare the user for upcoming movement. This object is described as a Virtual Guiding Avatar (VGA) and is significantly reducing side effects such as simulator sickness. The advantage of a VGA is, that the user can predict the upcoming motion and is therefore prepared to gaze in the direction in which the movement will happen. (Lin, Abi-Rached, & Lahav, 2004)

Realism and Detail of the Virtual Environment

Low visual realism of a Virtual Environment tends to reduce the symptoms of discomfort, whereas high realism increases the user's feeling of sickness. (Tiiro, 2018), (Pouke, Tiiro, LaValle, & Ojala, 2018) However, the presence of sickness does not have a significant effect on the immersion of the user. This means that the user will still feel present in the virtual situation even if the subject is experiencing cybersickness. (Tiiro, 2018)

Virtual Environment Travel

For the experiment the subjects travel from and to different locations and we want the users to feel as comfortable as possible during these actions. Also we want to keep the movement as simple as possible and limit unexpected behaviors (for example moving to a place where the participant should not). Another necessary condition to take into consideration is to choose a fast method, because we will have multiple teleports in one iteration and want to keep the time for one iteration as short as possible.

According to Browman et al. (1997) there are three components that constitute different travel techniques: Direction / Target Selection, Velocity / Acceleration Selection and Input Conditions.

Direction / Target Selection

There are basically two different ways of choosing where to travel.

The first way is the pointing technique, in which the either the implementation automatically selects, or the subject chooses a target location and then the participant teleports to it. This can be done by pointing at a place in the Virtual Environment or by placing virtual objects which indicate that the subject can teleport to this area.

The alternative is the gaze-directed technique, which lets the user decide in which direction the movement should happen. In the study of Brown et al. (1997) this is done by traveling in the direction the user is looking.

Velocity / Acceleration

Velocity / acceleration describes how the subjects gets to travel in the chosen direction or towards the chosen target. The travel can happen with discrete steps (1 to n) or continuous.

Discrete travel is like teleporting, but the range of the traveled distance can vary. If you choose only one step the user teleports to the target location and if you choose to do many the user is teleported to locations that lay between the origin and the target position. For example if a user teleports from the three dimensional origin with the vector (0,0,0) to the position described by the Vector (0,0,10) and the chosen steps are five, the first teleportation of the user would be to the position (0,0,2) the second one to (0,0,4) etc. until the subject reaches the desired position which in this case was (0,0,10).

Another way of discrete movement is to define a teleportation delta. If the participant again wants to travel from (0,0,0) to (0,0,10) and the delta is defined as (0,0,3) the user will teleport from (0,0,0) to (0,0,3) to (0,0,6) to (0,0,9) and then, because the magnitude of the difference-vector between the target and the current position of the user is smaller than the magnitude of the delta vector, the user would directly teleport to the desired position (0,0,10).

For continuous travel the idea is to move smoothly to the target or in the desired direction. Because the VR-Headsets cannot produce continuous movement due to the fact that it only displays a discrete amount of pictures, it works similar to the discrete travel but with a relatively (to the discrete movement) small delta, which is often affected by the time the last frame took to compute (delta time).

Example:

The origin is (0,0,0) and the target is (0,0,1). The base delta (without influence of the delta time) would be a vector with the magnitude of 1. The delta for a frame that took 0.01 seconds to compute (average for 100fps) would be a vector with the magnitude of 0.01 (equal to the base delta times the delta time – 1 * 0.01). So far, the delta vector is only defined by its magnitude and the delta vector that is being used to compute the travel would then be vector from the current subject position to the target position with the magnitude of 0.01. This movement will be called continuous in the following.

Input Conditions

There are different approaches for the user input. First, there is the possibility to travel without any user input, which is practical for some cases in an experiment, because then the system does not have to wait until the user interacts with it and the time for one iteration can be reduced.

Furthermore, there is the option to always wait for user input before traveling. This has the advantage, that the user can influence the speed of the actions happening.

Also, there is the option to start a travel with user input and afterwards the user either has the option to stop the movement / travel or he is not able to control the actions after starting them.

Conclusion and decision for travel

For our experiment we wanted to keep the comfort as high as possible. Browman et al. (1997) conclude that continuous movement is less comfortable than discrete teleporting. Also the results show that pointing techniques are faster than gaze-directed steering. However, the gaze-direction was more accurate and the pointing technique as used in the experiment of Browman et al. (1997) is harder to learn.

We decided to choose teleporting, because it is faster and with a discrete movement of one teleport directly to the target it is also comfortable. Furthermore, we eliminated the low accuracy by pre-defining the location where the subject would teleport to and added a fading-to-black animation before and after every teleportation. In the fading-to-black technique the screen fades to black in 0.75 seconds before teleporting and fades back to the view, also in 0.75 seconds. That way the users do not see the teleportation directly and so it is less sudden, which leads to an increased comfort of the user.

Interaction and time producing

After choosing the Oculus Rift as the VR-Headset and teleporting to a certain position we had to decide what kind of input we wanted to use. For the travel we would only need one button to start a teleportation. This also applies to time measurement. To answer the visual task, we would need two different answering possibilities with the chosen user input.

So, we decided to use the "Oculus-Remote". It has one primary-button and four buttons representing up, down, left and right, which is enough for our requirements of the study.

For teleportation and time measurement purposes the user should press the primary- and to answer the visual task the left- or right-button. The visual task is testing, whether the participants visual perception is performing better based on the theory of a faster ticking inner-clock. The procedure of the visual task will be described in greater detail, later in this thesis.

The time perception study

Current state of research

The phenomenon of overestimating durations can be found in so-called oddball studies (Pariyadath und Eagleman, 2007). An oddball is defined as an unusual event / stimulus like falling of a rooftop. It could be shown that oddball overestimation is linked to the P3, which is an event-related potential (Ernst, et al., 2017). The thesis says, that shortly after being presented an oddball the P3 will occur. Also it shows that if the P3 occurs, the participant overestimate durations.

Overestimation of time means, that the so called "inner clock" ticks faster than usual, when presented an oddball. The inner clock theory describes a clock that works with so-called "pulses", which are generated and registered internally (Ernst, et al., 2017).

(Pariyadath & Eagleman, 2007) concluded after a series of tests, that the perception of time is not one system inside the human brain, but rather split into many clocks that usually work synchronized. So, an oddball may affect the emotional perception of time, but may not affect (for example) the visual processing time of the brain.

According to the Coding-Efficiency Theory the processing of a stimulus depends on the stimulus given. A frequently experienced stimulus, that requires little attention, is being processed more effectively and is therefore transmitted faster than a stimulus experienced less often. New stimuli will transmit slower and therefore time is perceived slower (Eagleman & Pariyadath, 2009) (Pariyadath & Eagleman, 2007).

Here the formulations should be chosen carefully, because the processing of a stimulus presented for one second would feel longer than one second, meaning that the inner clock is ticking faster than usual. For reproduction, when presented an oddball and a duration at the same time, the duration will be received as longer than it is.

But for production, as the inner clock ticks faster, the subject would create a shorter interval, when presented an oddball.

A similar study was done by Stetson et al. (2007) where the participants were falling off a tower and were advised to guess the time of the fall. The perception of their own fall was 36% longer than the estimated duration of the fall of others, judged from the ground. In this study the measurements were limited, due to the fact, that people were falling in the real world. For our experiment we will also measure and analyze the perception of time during a fall in comparison to standing still.

Also, they used the fact, that if two images alternate fast the visual brain cannot differ between them. The participants were shown a display on which an image of a number and the negative image of the number was shown. If the images alternate rapidly, the subjects were not able to tell what number is being displayed. The core idea was, that the brain is working too slow to differ the two images and that if the participants were presented a specific stimulus their visual processing would work faster, resulting in the participants correctly identifying the numbers on the display.

For their experiment they released the subjects from a tower to fall 31m into a net. The display was attached to their forearm. Before the fall the threshold in which the image and it's negative merged, was identified. For the fall this threshold was speeded up and the participants had to try to read the digit from the display as they were falling. The expectation was, that the participants could identify the displayed number, because their visual perception was more efficient due to the fall. The result for this experiment however was, that the participants could not perform better in terms of identify the numbers during the fall. The in-flight performances were comparable to the ground-based results. They conclude that the visual processing of the brain is not influenced by the subjective time speeding up, but instead it is a phenomenon in which the emotional memory of the people may lead to varying time perception.

Objectives

For the experiment we have a within subject design, because there is a lot of variance with different participants, such as different strength of fear of heights, time perception accuracy, skull thickness etc.). For an in subject design all subjects participate in the same experiments with the same conditions. We will manly test the difference of the produced time between the results collected while falling, staying and flying (first objective). Also, we expect the effect to weaken over time (second objective), due to the fact, that the participants get to know the experience. They will experience staying, falling and flying multiple times and at the end of the study it should be more familiar than at the beginning.

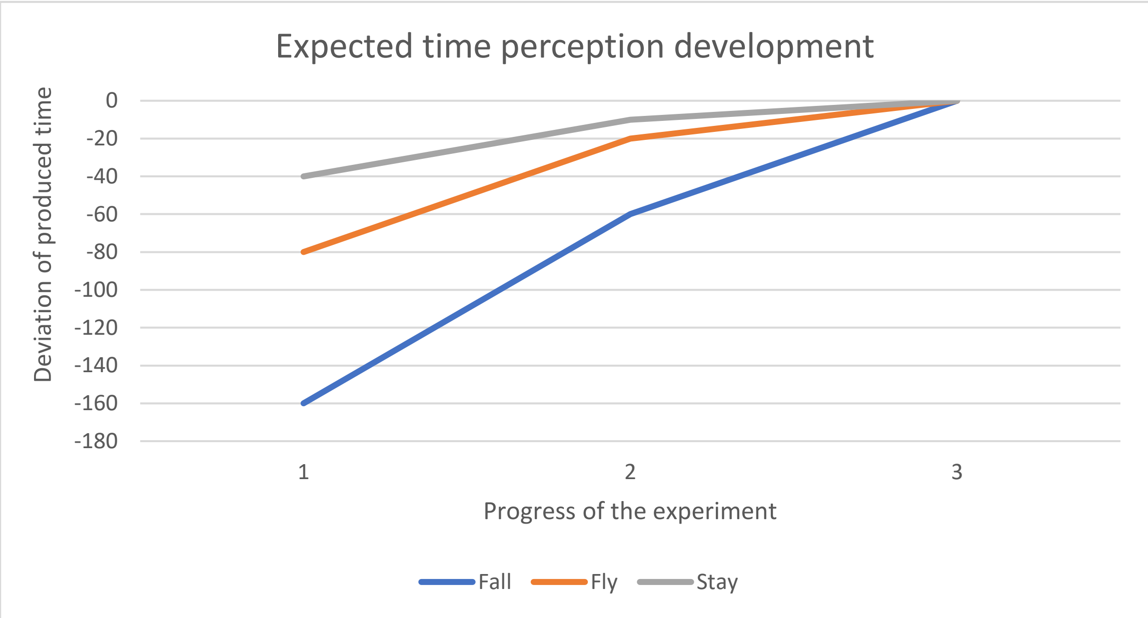

Figure 1. Expected development of time perception. The produced duration of the fall is expected to be the most off, the staying should be about the estimation and the fly is expected to be in between.

Also, the P3b value should be higher, when the participants produce a shorter time period than usual (third objective).

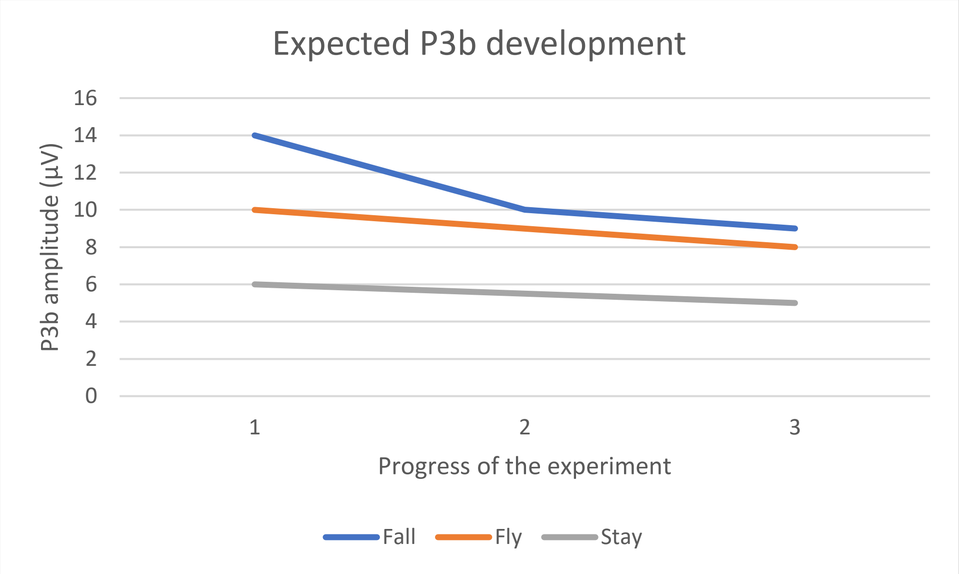

Figure 2. Expected P3b development. The P3b is expected

We expect a shorter produced duration while falling and we use standing still and flying upwards as control conditions. For all conditions the visual impressions should be as similar as possible in order to remove other stimuli that may influence the measurements.

Also, we included a visual task similar to the experiment of Stetson et al. (2007) where the participants will be presented 24 fast alternating letters in a randomized order. The task is, to identify if it contains the letter "C" or "G" (fourth objective). Only one of the letters will be included at one letter set.

EEG measurement

For the experiment we used a BIOSEMI Active-Two system (BioSemi, Amsterdam, The Netherlands) with 64 Ag-AgCl electrodes from channels Fp1, AF7, AF3, F1, F3, F5, F7, FT7, FC5, FC3, FC1, C1, C3, C5, T7, TP7, CP5, CP3, CP1, P1, P3, P5, P7, P9, PO7, PO3, O1, Iz, Oz, POz, Pz, CPz, Fpz, Fp2, AF8, AF4, AFz, Fz, F2, F4, F6, F8, FT8, FC6, FC4, FC2, FCz, Cz, C2, C4, C6, T8, TP8, CP6, CP4, CP2, P2, P4, P6, P8, P10, PO8, PO4, O2, as well as the left and right mastoid. Yet because of the virtual reality headset not all electrodes could be brought into place and had to be left out. This altered from test subject to test subject.

The DRL (Driven Right Leg) and CMS (Common Mode Sense) electrodes were used as reference and ground electrodes. All electrodes were off-line re-referenced to averaged mastoids. The EEG was continuously recorded at a sampling rate of 512 Hz.

Iteration Design

At the beginning of each iteration the participant stands in the middle of a rooftop. At this starting position the subject cannot see the ground. But due to visual clues, such as other big buildings, it is clear that the rooftop is high above ground level.

The second position is at a plank, which can be seen from the starting position and is at the edge of the rooftop. The participant is being told to press the trigger button of the given remote to start the first teleport. After pressing the button, the teleport happens as described in the section “Virtual Environment Travel”.

At the time the teleport has finished, and the vision is back to normal, an acoustic and a visual signal is shown to the subject. These two signals are representing the action to follow. The visual clue is an arrow pointing up for flying, down for falling or a horizontal line for staying. At this moment the participant first knows, what the action for this iteration will be. Also, the first time-measurement is beginning right after the sound signal. The participant has to produce the duration (one second) by pressing the button on the remote one second after the sound signal.

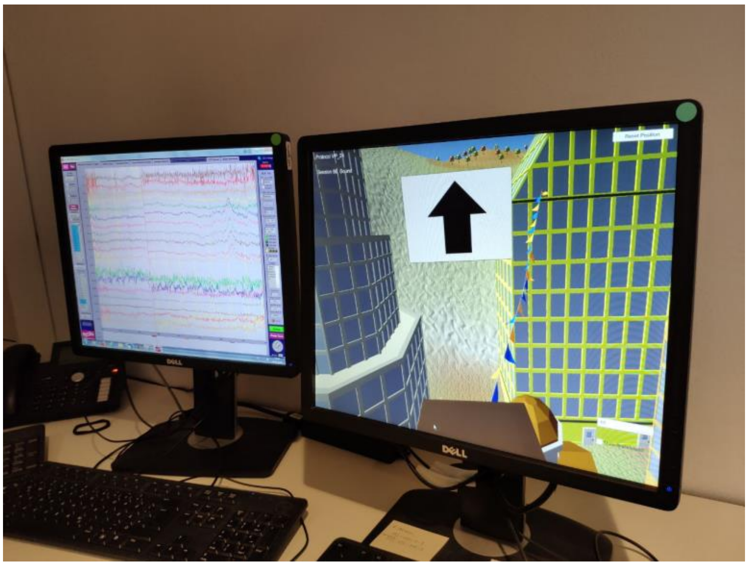

Figure 3. Live EEG Data (left monitor) and Up-Arrow indicating the fly action (right monitor). The whole simulation was displayed live at a separate monitor, outside the VR-Headset, with additional information about the current iteration, the current iteration index and options for resetting the view of the participant.

Afterwards the first time-measurement is done and the visual task is initiated. It is presented by a screen on the right of the subject and it starts once the participant presses the trigger. When the visual task is finished, the subject has to answer if it contained a “C” or a “G” by pressing the “left” or “right” key on the remote.

At the time the visual task is finished, another sound signal is being presented, which indicates the start of the action (fall / stay / fly). While the action is happening another auditive signal is marking the beginning of the second time measurement. This is the one we expect to vary depending on the given action. After this measurement is finished the subject will be teleported back to the start position and the next iteration begins.

Experiment Design

The experiment consists of 4 blocks, whereas the first consists of 40 iterations, the second and third of 60 and the fourth one of 80.

First of all, the subject participates in a rehearsal, so that the participant gets to know the procedure. This is done outside of the Virtual Environment. Also, at the beginning and before every block, the subject trains to produce one second as precise as possible with a separate software that is developed for that purpose. In that software the subject must produce one second interval by pressing the left mouse button after an auditive signal. Then the participant gets feedback if the produced interval was too short or too long. In order to train the subjects for producing the best possible time intervall we used an algorithm which shortens the admitted variance after many accurate answers.

For additional analysis of the measurements a fear of heights score is determined through a questionnaire.

Additional Information about the experiment

As shown in Figure 3 the current status and picture of the participants were displayed on a separate monitor. The displaying information contains the name of the current protocol on the top left side of the screen. Underneath the protocol name is a text block with the current Session index and the state of the iteration, such as “Sound” meaning that the participant is hearing a sound, “Visual Task” which indicates that the visual task is being displayed, or “Action” which is being displayed while an action (fall, fly or stand) happens.

Also, there is the possibility to reset the position of the participant’s view in the virtual environment. This is necessary if the participant is standing in a different location at the time the application is starting than while the experiment is ongoing. This way the camera position is not at the desired location. To make sure that the subject is placed on the plank and not next to / underneath / high above it, the position has to be reset once the participant is at the “real-world location” where the experiment will take place.

The idea behind the reset position is that in the application, the position which is representing “standing on the plank” is defined. Because of the way the Oculus SDK works in unity, the camera position, which is representing the user’s view, cannot be reset to a specific position itself, but instead the Oculus SDK manages all positional updates and overrides other modifications. However, it is possible to reset the position of the parent of the camera object. By using object “A”, which is the parent of object “B”, while B is the parent of the camera object. The position of object A is always set to the determined position of the application, whereas the relative position of B is set to the inverted vector of the position of the camera, once the “reset position”-button is pressed.

Additionally, it is possible to modify the speed of the visual task by typing the duration in milliseconds in the provided input field. This feature was not used in the experiment.

Also, it is possible to mute the sound which indicates the start of an action. This feature however was also not used in the final experiments.

During the whole experiment the participants were connected to an EEG, which measured their brain activity (Figure 3. Left monitor)

Results

In the following the results of the experiment will be presented. The data underly measurements of 23 participants. At the time this is written 24 subjects participated in the experiment and 19 of them finished it. For two of the five participants, that did not finish the experiment, the experiment was aborted due to time reasons and the other three subjects aborted due to simulator sickness. For 4 of the five participants that aborted early enough data was collected, so that it could be taken into consideration.

Like the experiment, the results were collected and evaluated in cooperation with Florian Schwarzmeier and Dr. Benjamin Ernst. For the data analysis we used T-Tests and analysis of variance – ANOVA.

Production of durations

Overall the produced durations were clearly longer than the given duration of one second. The mean was around 1.35 seconds. Also, there was a significant difference between the productions of the first and the second time measurement – $F(2,22) = 260{,}61$, $p < 0{,}0001$. The first measurement was at the rooftop and on the plank. Whereas the second one was while the action was happening (fall, fly, stay). The reason behind this is not clear, but it may relate with the different sounds, that were used. For the first measurement we used one of three different sounds, which referred to the action, that will happen and the second sound was another / a fourth one.

First measurement

For the first measurement, if the signal for a falling or flying action occurred, the participants produced a marginal significant shorter duration - $F(2,21) = 4,66$, $p = 0,015$ in comparison to the staying action:

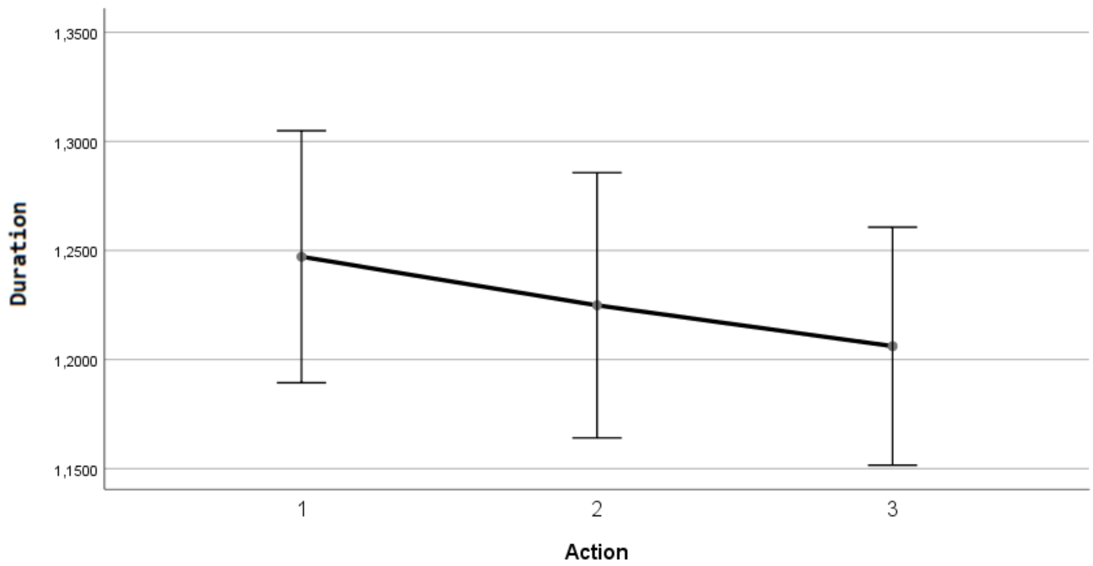

Figure 4. Mean produced durations of the first measurement. For the actions (X-Axis) 1 equals staying, 2 falling and 3 flying. On the Y-Axis the mean values of the produced time are displayed. The bars represent the standard error.

The produced durations after the notification of an upcoming fall were marginal significant shorter than the ones for staying - $t(22) = 1,70$, $p = 0,10$. The results for flying, compared to the produced durations of staying were significantly shorter - $t(22) = 3,18$, $p = 0,004$. But flying compared to falling did not have a significant difference - $t(22) = 1,31$, $p = 0,20$.

Second measurement

While the action happened, the second measurement was taken. The effect was significantly shorter for falling and flying than it was for staying - $F(2,21) = 10{,}53$, $p < 0{,}001$. The results for this second measurement were similar to the results from the first one.

While falling the participants produced significantly shorter durations, compared to staying - $t(22) = 3{,}71$, $p < 0{,}001$. The durations for flying compared to standing were also significantly shorter - $t(22) = 3{,}29$, $p = 0{,}003$. Again, flying compared to standing did not have a significant effect - $t(22) = 0{,}40$, $p = 0{,}69$.

In conclusion falling and flying were both significantly influencing the time perception of the participant, whereas staying did not have a significant effect on it.

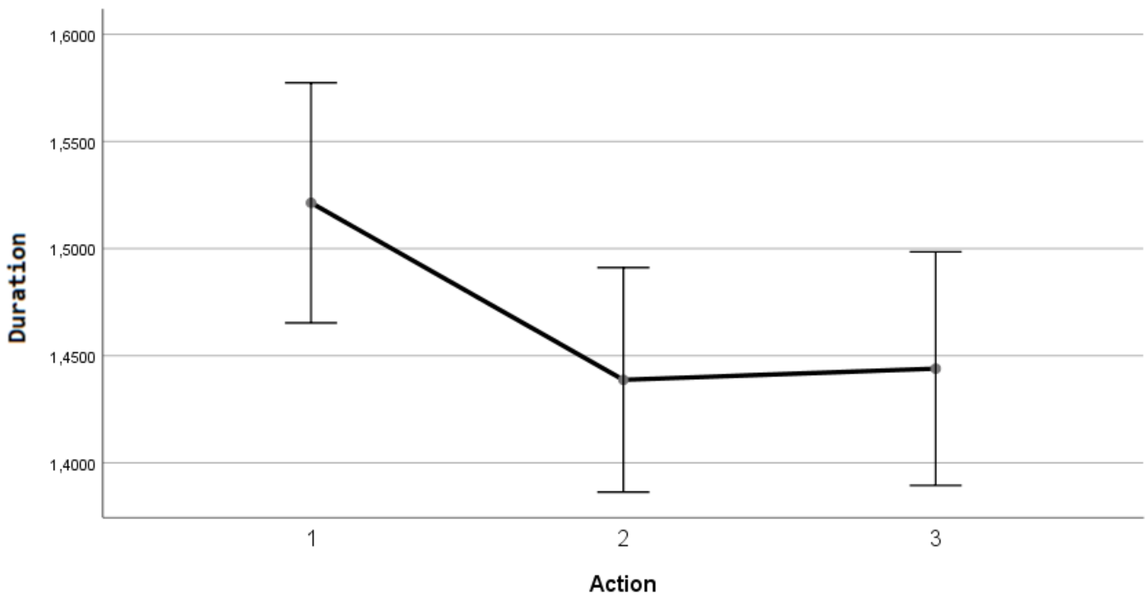

Figure 5. Mean produced durations of the second measurement. Action 1 represents staying, action 2 falling and action 3 flying. The Y-Axis is the produced duration in seconds and the bars display the standard error.

Visual Task

For the visual task no significant effect, based on the actions, was produced - $F(2,21) = 1,48$, $p = 0,24$. Still a numerical trend is identifiable. This trend is, that the best results were achieved before falling, and the worst before staying. This is what we expected; however, it is not a significant effect. Therefore, it will not be discussed in greater detail.

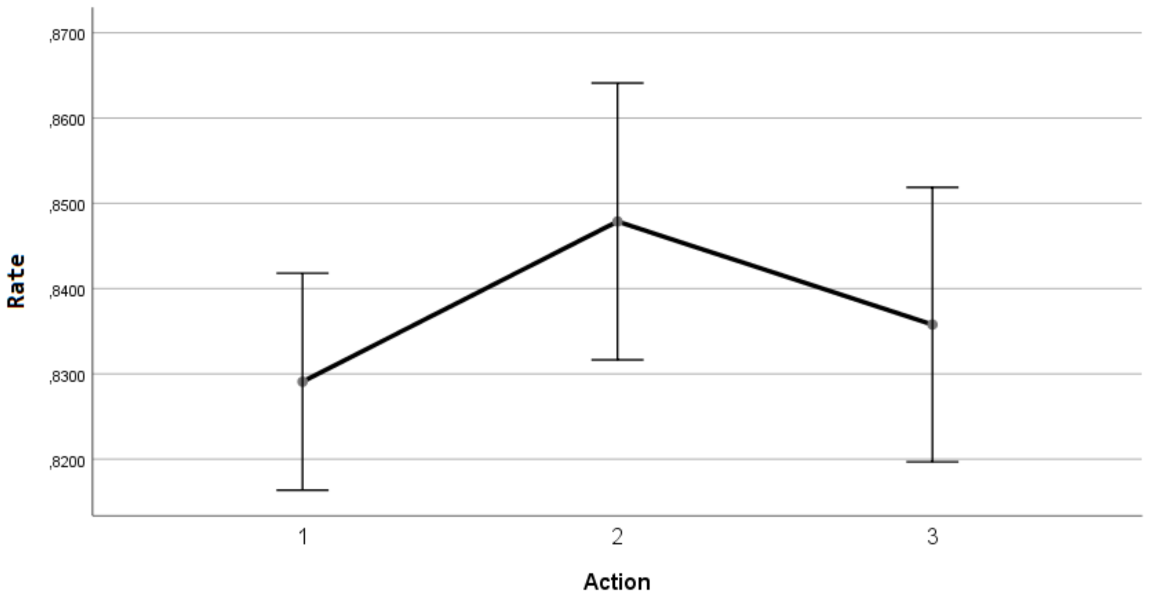

Figure 6. Visual Task results. Action 1 represents standing, action 2 falling and action 3 flying. The Y-Axis is the rate, which represents the correct answers (relative to the total answers in that quarter) given in percent divided by 100. The bars represent the standard error.

EEG and VR

The combination of a VR-Headset and EEG was much more complicated than expected. The headset applies pressure to some electrodes, which adds much noise to the collected data. Also, it is uncomfortable for the participants. The noise is a result of (even small) head movement, which is necessary for the execution of the tasks given in the virtual environment.

This results in noise of more than 100µV, whereas the normal brain activity is around 10µV. The usual procedure would be to just leave the collected information of these electrodes out, but the affected electrodes are at the back of the back of the head and are important for our analysis.

Also, the mounting strap on top of the head can apply pressure to other important electrodes, which results in more noise on important areas. So far, the measured data is getting free from noise, however no results for the P3b question were found. The VR-Headset's electronic did not disturb the EEG data in the frequencies we analyzed. For future studies we would suggest using a ring of rubber or foam to prevent the VR-Headset brackets from moving the electrodes.

Visual Task over time

The effect of the Visual Task over time shows no significant relations to the passed time. Meaning that the participants did not get better or worse during the execution of the experiment. Nor was there a significant relation to the upcoming actions. But instead there was a significant interaction - $F(2,17) = 3{,}08$, $p < 0{,}008$.

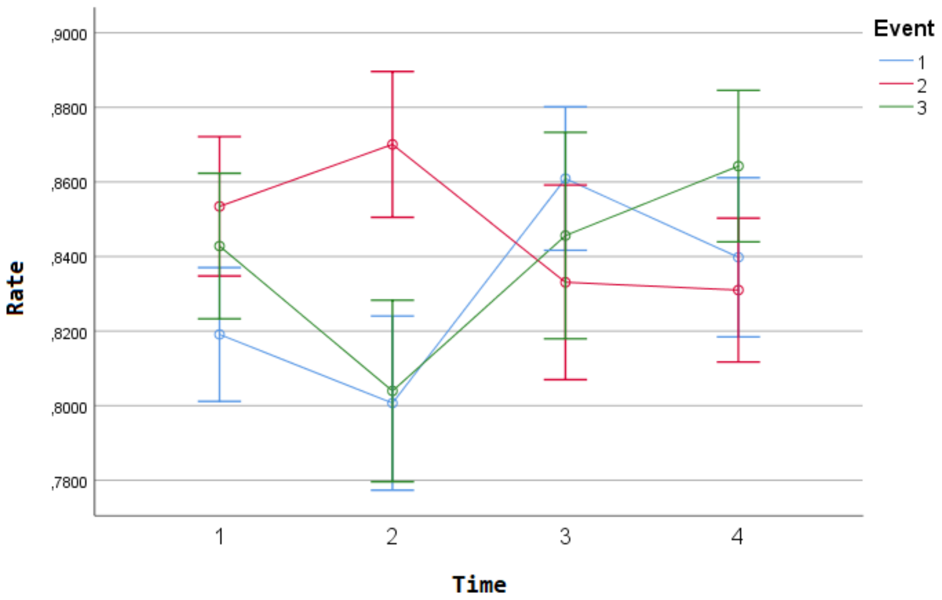

Figure 7. Visual Task: rate over time. Event 1 represents, that the signal for staying was displayed, Event 2 for falling and event 3 for flying. The time represents the different quarters of the experiment. Each quarter contains about 20 measurements for each action. The Y-Axis displays the rate, which represents the correct answers given (relative to the total answers in that quarter) in percent divided by 100. The bars represent the standard error.

At first, the signal for an upcoming fall results in a better performance, compared to the signal for upcoming standing. For the second quarter the rate is higher, compared to flying, too.

However, for the third and fourth quarter the effect reverses and the rate for correct results, for falling become the lowest, whereas the results for flying become the highest. With this data no effect can be concluded and there is no reason, which would explain this development.

Production over time – First measurement

To compare the produced durations over the time of the experiment only complete data is usable. So, the following data is based on the data sets of 19 participants.

For the first measurement (standing on the plank before the visual task and action) no significant results were measured - $F(3,16) = 1{,}83$, $p = 0{,}18$. Only a numerical trend; that the durations of the produced intervals got longer, is identifiable.

For the first measurement, a stronger significant effect depending on the upcoming action was recognized, in comparison to the mean values - $F(2,17) = 10{,}01$, $p < 0{,}001$. This means that the people, who aborted the experiment and were not considered in this analysis, reduced this effect.

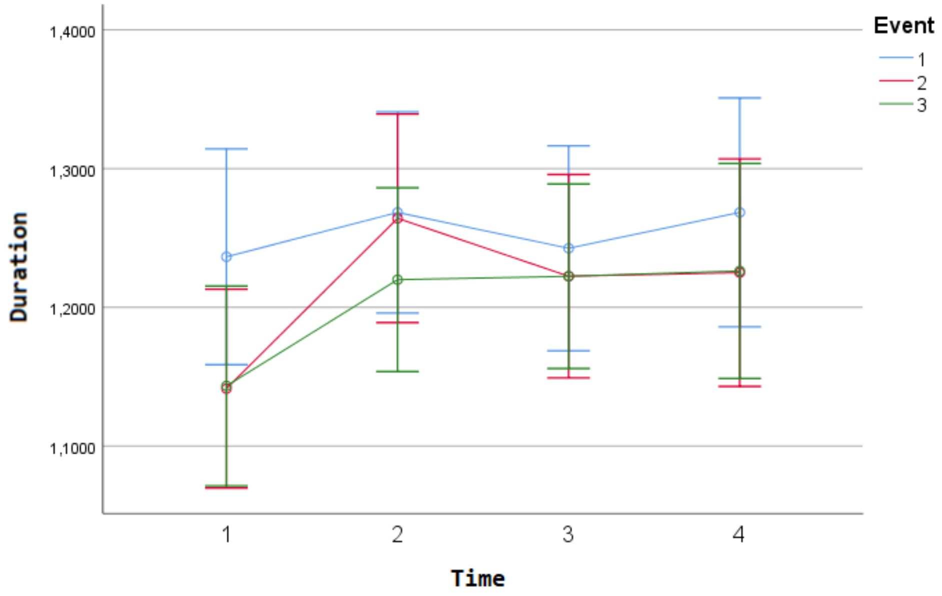

Figure 8. First measurement: Durations over time. Event 1 represents, that the signal for staying was displayed, Event 2 for falling and event 3 for flying. The time represents the different quarters of the experiment. Each quarter contains about 20 measurements for each action. The Y-Axis represents the mean value of the produced time in seconds. The bars represent the standard error.

Production over time – Second measurement

For the second measurement, not only the effect of the action was changing the produced durations significantly - $F(2,17) = 8{,}80$, $p = 0{,}003$. But also, the time spent in the Virtual Environment had an effect, which is significant - $F(3,16) = 3{,}35$, $p < 0{,}025$. During the progress of the experiment, the participants repeatedly experienced staying, falling and flying, and the produced durations got longer.

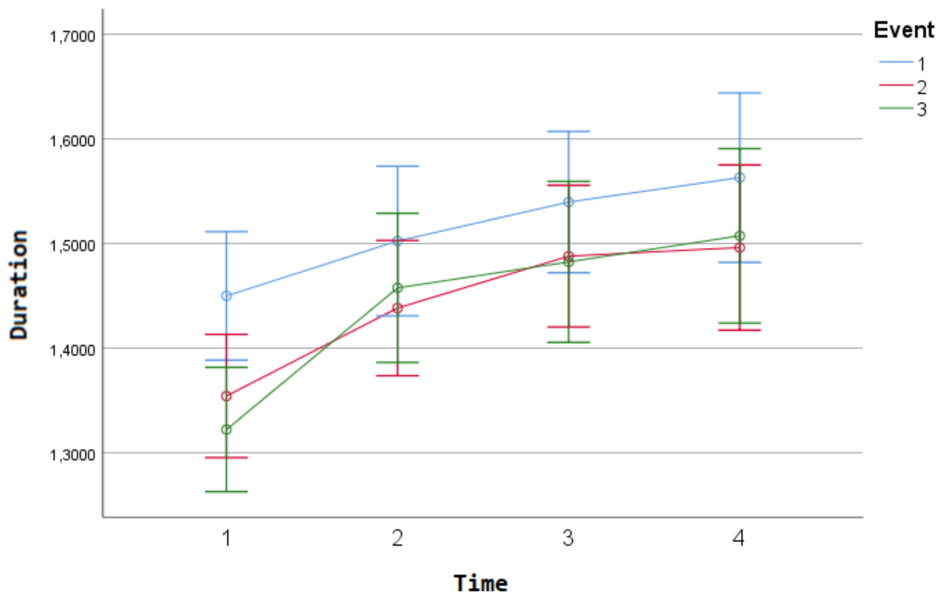

Figure 9. Second measurement: Durations over time. Event 1 represents, that the signal for staying was displayed, Event 2 for falling and event 3 for flying. The time represents the different quarters of the experiment. Each quarter contains about 20 measurements for each action. The Y-Axis represents the mean value of the produced time in seconds. The bars represent the standard error.

This is the effect we expected. In the first place the participants were experiencing a new situation and because of that, the inner clock ticked faster. Over time the subjects got used to the actions and in conclusion the effect weakened. The effect is also significant for staying - $F(6,13) = 2{,}26$, $p < 0{,}05$, which could be explained by the fact, that the "overall situation" was exciting at first, but the excitement also decreased over time.

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