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Kinetosis Analyzation of the Symptoms Occurrence in combination with Eye Tracking

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Abstract

The general kinetosis is a well-known problem. Besides common types of kinetoses such as seasickness, there are visually induced kinetosis. One of these special forms of kinetosis is caused among others in virtual reality – especially when using a head mounted display. Common symptoms are nausea, blurred vision or dizziness. There are several theories about the origin of motion sickness. In the context of virtual space, the rest frame theory is very interesting for the examination of motion sickness. Basically, the theory states that human beings are looking for fixed points in order to maintain their equilibrium. The paper investigates the detection of symptoms with the accumulation of fixed points. We used a head mounted display including eye tracking to collect the data of our subjects. A total of 26 subjects participated in the study. The Motion History Questionnaire determines the general motion sickness susceptibility, and after staying in virtual space, the Simulator Sickness Questionnaire is used to analyze the symptoms. The eye tracking data from the virtual space was evaluated and compared to the results of the Motion History Questionnaire and Simulator Sickness Questionnaire. The evaluation of the eye data shows differences between the subjects with a tendency to motion sickness and those without. The data indicates that it is indeed possible to measure the occurrence of kinetosis in the virtual space with eye tracking data.

Keywords: Eye Movement, Kinetosis, Motion Sickness, Rest Frame Theory, Virtual Reality Sickness.

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Introduction

Kinetosis is derived from the Greek word ‘kinein’ (‘to move’) (Most and Martin Tegenthoff, 2004). The term kinetosis summarizes various clinical pictures. In the current International Statistical Classification, ICD-10, catalog of the World Health Organization (WHO), the kinetosis itself is represented under the symbol T75.3. Under this general term ‘Air Sickness’, ‘Seasickness’ and ‘Motion Sickness’ are listed. Besides normal kinetosis, like seasickness or travel sickness induced through motion, there are also types of kinetoses induced by a visual stimulus like the virtual reality sickness, simulator sickness or gaming sickness. Those are also called Visual Induced Motion Sickness (VIMS).

There are some minor distinctions in the causes of pseudokinetosis. Same as for the motion induced sicknesses. There is no clear definition for the cause of this illness. However, it often occurs in conjunction with the illusion of movement of the body. This is a clear difference to motion sickness, because here the body experiences a real physical movement (Lawson, 2014).Vection, which is one of the causes for a visual induced motion sickness, does not only occur in virtual space but it is stronger in the virtual world than in the real world.

At the same time, vection can be reduced more easily in virtual space than in the real world. It can be reduced through various things such as the field of view (*FOV*) or setting the frame rate in the virtual environment. Therefore, in conclusion, the main differences of a visual induced motion sickness and a normal motion sickness are:

Visual induced Motion Sickness:

- Usually, organism is at rest (calm, upright holding of the head (Thieme, 2018))
- Triggered by fast sequence of images.

Motion Sickness

- Includes physical locomotion (Grattenthaler D.-P. A.-P., 2018)
- Triggered by fast sequence of images.

Nowadays, the topic of kinetosis in virtual environments is well-known and is researched from various viewpoints, as you can see in the bibliography (Grattenthaler, 2006; Hammer, 2016; IuG15-VR, 2015; Kim et al., 2008; Lin et al., 2002; Sharples et al., 2008; Tanaka and Takagi, 2004).

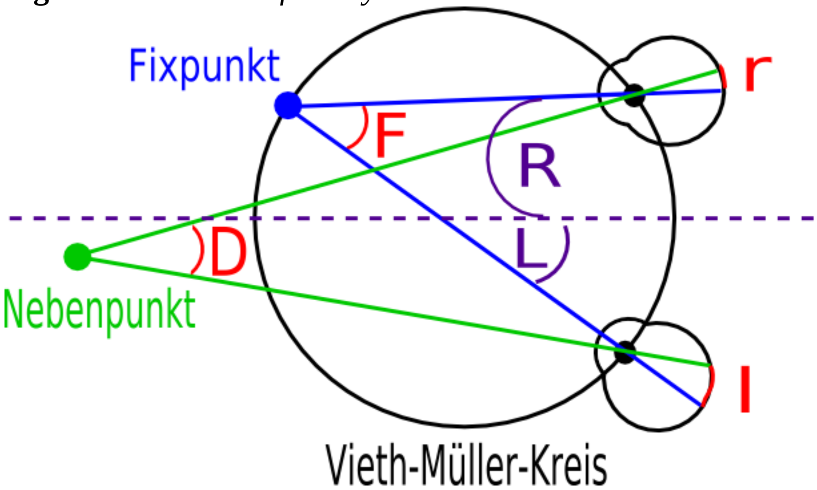
One of the newest theories about the appearance of motion sickness is the Rest-Frame-Theory. Jerrold Prothero postulates in his dissertation ‘The role of rest frames in vection, presence, and motion sickness’:

‘From a mathematical point-of-view, our strong perception that certain things are stationary is quite strange. Given a relative motion between two entities, it makes as much sense to interpret either (or neither) as stationary’ (Prothero J. D., 1998).

He explains it with a simple example: if you move your hand back and forth in a room, the hand or the room can be perceived as stationary. In mathematical terms, both variants would be correct, but our nervous system perceives the environment differently.

The rest of the frame is defined as a stationary reference system (Berg, 2014) in our brain. Other movements are relativized to the stationary object. The user chooses a fixed point and now assumes that this point is stationary. This creates an illusion of stability. To ensure stability, the human body has several systems that interchange. However, the virtual world of the body has the problem, that it can no longer activate the correct systems. If the user takes a fixed point, for example in a virtual reality game, these conflicts can be reduced. A fixed point could be a stationary point on the horizon. If a point is considered with the eyes, then this is the fixed point. The image resulting from this point is projected centrally on the retina pit (see Figure 1).

Figure 1. *Fix Point of the Eyes*



(Blue: fix point, green: side issue)
Source: https://glossar.hs-augsburg.de/Datei:Vieth2.png.

This illusion can be compared to standing on one leg. If a person attempts to stand on one leg without a fixed point, then it is difficult to stand completely still and not to waver or even completely lose balance. If a fixed point is searched for and focused on, it is much easier to stand on one leg.

Prothero also suggests that visual background manipulations in a virtual environment may reduce the motion sickness caused by a simulator.

This theory got substantiated by James Jeng-Weei Lin, Habib Abi-Rached, Do-Hoe Kim, Donald E. Parker and Thomas A. Furness in the article '*A 'Natural" Independent Visual Background Reduced Simulator Sickness*'. They used a visual background with none, less and many clouds as fix points. With many clouds the RSSQ score was lowest (Prothero, M & Furness, & Don & J Wells, 1999) (Lin, Abi-Rached, Kim, Parker, & Furness, 2002).

This leads to the assumption that a lack of fixed points is one reason that causes virtual reality sickness. In this article, we want to determine the role of fixed points during a person´s time in a virtual environment.

Methodology

An eye tracking profile in the FOVE (see below) (Fove, 2018) launcher is created for each subject. The subjects then use the head mounted display in a virtual environment. While wearing the head mounted display the vectors of the left and right eye are recorded and stored in a .csv file. This file is being analyzed by a *Phyton* script.

Some individual coordinates of the eye tracking data were stored:

- cx - converged X-coordinate of the eyes
- cy - converged Y-coordinate of the eyes
- cz - converged Z-coordinate of the eyes
- lx - X-coordinate of the left eye
- ly - Y coordinate of the left eye
- lz - Z coordinate of the left eye
- rx - X-coordinate of the right eye
- ry - Y-coordinate of the right eye
- z - Z coordinate of the right eye
- timeinseconds - time in seconds
- sick – 'o' if the subject does not notice any symptoms, 'x' if the subject feels uncomfortable. The subjects can press CTRL on the keyboard when they fell any discomfort.

Before the experiment starts, each subject received a Motion History Questionnaire (Griffin & Howarth, 2000) to analyze his previous history of kinetosis (for example known travel sickness). After the experiment we used the Simulator Sickness Questionnaire to validate the experienced sickness.

Apparatus

<u>Eye Tracking</u>

- The Japanese FOVE-VR glasses are the first eyeglasses to enable eye tracking without any additional hardware.
- The following hardware specifications are offered by the FOVE:
    - 2K resolution
    - Tracking Systems:
        - Infrared measurement - the position of the head is tracked via this one
        - Eye Tracking
        - Orientation tracking inertial measurement
    - The field of view is up to 100 degrees
    - Frame rate of 70 fps
    - SDK with compositor - the compositor reflects the current content on the monitor, which is displayed on the VR glasses

  - Plugins for popular game engines such as Unity, Unreal and Xenko
  - Compatibility with STEAM-VR
- The package of FOVE includes a camera that tracks the positions of the head on which the head mounted display is located.
- The hardware requirements for the connected PC are as follows:
  - GPU: NVIDIA GeForce GTX 970 / AMD R9 290 or better (desktop PC)
  - CPU: Intel Core i5-4590 or better
  - RAM: 8GB or larger
  - Connectors: HDMI 1.4 / USB 3.0 / USB 2.0 x
  - Operating system: Windows 8.1 64-bit or Windows 10 64-bit

Coding

Eye Tracking - C++

For eye tracking the Fove SDK was used. The file ‘DataExample.ccp’ was adapted to read out the vectors of the eye movements and to save them in a CSV file. This was provided by the official FOVE development team. They offer their code on Github https://github.com/FoveHMD/, FoveCppSample, including a MIT License.

Heatmaps – Python

To evaluate the collected data, Python was used with the following libraries:

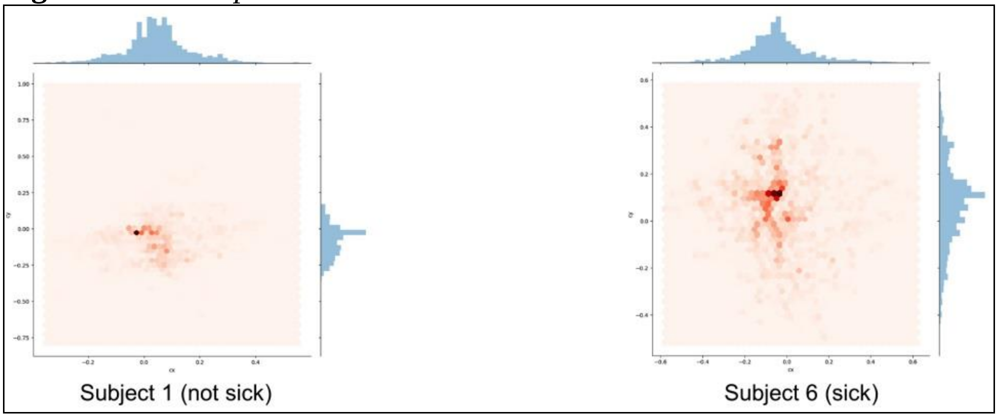
- *seaborn*, visualizes data e.g. as a heatmap
- *pandas*, manages, analyzes and manipulates data
- *pyplot*, creates displayable figures to display

Findings/Results

Evaluation

A total of 26 subjects participated in the trial. 20 of the subjects were male, the remaining participants were female. The average age was 29.53 years. Six subjects showed several symptoms of motion sickness, another two showed symptoms of increased motion sickness. The eight subjects suffering from symptoms also showed a different distribution of fixed points than the sixteen participants without symptoms. As an example, we see a subject with symptoms and a subject without (Figure 2).

Figure 2. *Heatmap*



Source: Own Experiment, Seaborn Heatmaps.

Motion History Questionnaire Evaluation

By evaluating the results of the MHQs of the concerned persons, we have classified the results into the following aspects:

- $T_{yr.}$ - Travel Frequency in the past year. The result is calculated from the sum of the answers from question one. If a subject crossed never this was counted as zero. The other values are in ascending order from one to six, where six corresponds to a cross at 256+.
- $I_{travel(yr.)}$ - disease incidence during travel in the past year The disease frequency is the sum of question two of the MHQs. As with question one, never is counted as 0 and 16+ as 6.
- $V_{travel(yr.)}$ - frequency of vomiting while traveling in the past year The answers in question three are used to determine the frequency of vomiting in the past year. The calculation of the values is the same as for the incidence of vomiting last year.
- $I_{susc.(yr.)}$ - susceptibility to kinetosis of travel in the past year For the calculation of $I_{susc.(yr.)}$ the results from questions one and two are used.
  $I_{susc.(yr.)} = \sum \frac{(S_I/S_T)}{N}$
  - T_{yr} is the sum of the first question ($\sum S_T$)
  - $V_{travel(yr.)}$is the sum of the second question ($\sum S_V$)
  - N corresponds to the number of means of transport
- $V_{susc(yr.)}$ - susceptibility to nausea with vomiting during travel in the past year To calculate the vulnerability for the past year, the sums of questions one and three are divided, and the result is divided by the number of means of transport used.
  $V_{susc.(yr.)} = \sum \frac{(S_I/S_V)}{N}$
  - T_{yr} is the sum of the first question ($\sum S_T$)
  - $I_{travel(yr.)}$is the sum of the second question ($\sum S_I$)

  - N corresponds to the number of means of transport
- V_{total} susceptibility of vomiting for all means of movement the answers from question 11 are used to determine if the subject had ever vomited while traveling with a means of transport.
- M_{total} - susceptibility for motion sickness in total

To determine a general vulnerability, different results of individual questions are summed up. The description of the individual sums and the associated questions are shown in the following table (Table 1):

Table 1. *Breakdown MHQ M_{total}*

symptoms	label	questionnaire
Heat / Sweat	$\sum S_{hot}$	4
Headache	$\sum S_{head}$	5
Paleness	$\sum S_{pallor}$	6
FLOW FLOW	$\sum S_{water}$	7
Sleepy	$\sum S_{drowsy}$	8
Dizzy	$\sum S_{dizzy}$	9
Nausea	$\sum S_{nausea}$	10
Vomiting	$\sum S_{vomit}$	11

Source: Own Experiment, Seaborn Heatmaps.

$$\sum M_{total} = \sum S_{hot} + \sum S_{head} + \sum S_{pallor} + \sum S_{water} + \sum S_{drowsy} + \sum S_{dizzy} + \sum S_{nausea} + \sum S_{vomit}$$

Susceptibility to motion sickness on land transport during the past year, while traveling on land - V_{land}

For this purpose, only the values of cars, bosoms, coaches and trains for questions 4 - 13 are evaluated.

$$\sum M_{ltotal} = \sum S_{Ihot} + \sum S_{Ihead} + \sum S_{Ipallor} + \sum S_{Iwater} + \sum S_{Idrowsy} + \sum S_{Idizzy} + \sum S_{Inausea} + \sum S_{Ivomit}$$

Susceptibility to motion sickness in the past year while traveling by ship / boat or aircraft (V_{nland})

Only the values of small boats, ships and airplanes are evaluated on questions 4 - 13.

$$\sum M_{nltotal} = \sum S_{nlhot} + \sum S_{nlhead} + \sum S_{nlpallor} + \sum S_{nlwater} + \sum S_{nldrowsy} + \sum S_{nldizzy} + \sum S_{nlnausea} + \sum S_{nlvomit}$$

In addition to the individual evaluation of the subjects and the later comparison with the SSQ, the subjects can be divided into the groups *sick* and *unsick*. Dividing the groups makes it easier to compare the evaluations of the MHQ of the two groups (see Tables 2 and 3).

Table 2. *MHQ Median, Minimum, Maximum of the Group 'Sick'*

Evaluation method	$I_{susc.(yr.)}$	$V_{susc.(yr.)}$	V_{total}	M_{total}	V_{land}	V_{nland}
Average	0.224	0	0.25	10.125	9.25	0
Median	0.058333333	0	0	9	9	0
Maximum	1.2	0	1	17	16	2
Minimum	0	0	1	1	-2	0

Source: Own Experiment, Evaluation of the MHQ Data.

Table 3. *MHQ Median, Minimum, and Maximum of the Group 'Unsick'*

Evaluation method	$I_{susc.(yr.)}$	$V_{susc.(yr.)}$	V_{total}	M_{total}	V_{land}	V_{nland}
Average	0.0571	0.00042	0.28	5.11	3.22	1.167
Median	0	0	0	4	2.5	0
Maximum	0.5	0.008	1	13	9	8
Minimum	0	0	0	-1	-1	-2

Source: Own Experiment, Evaluation of the MHQ Data.

If the median of the evaluation is taken into account, it quickly becomes clear that there is a much smaller distribution of the values among the subjects not affected by motion Sickness.

Overall, the values of the *sick* group were always in a very high range for the entire motion sickness (M_{total}). The maximum of M_{total} is 17 for the subjects with symptoms and 13 for the symptom-free subjects. The mean of the two groups also shows that the subjects with motion sickness are on average at *10.125*, while the subjects without symptoms are on average at the M_{total} at 5.11 (Griffin & Howarth, 2000).

Simulator Sickness Questionnaire Evaluation

After the experiment, we evaluated the experienced symptoms with the Simulator Sickness Questionnaire. Every subject got a list of possible symptoms and had to rate the appearance of these symptoms from zero (no symptom experience) to three (heavy symptom experience). The symptoms were:

1. General discomfort
2. Fatigue
3. Headache
4. Eye strain
5. Difficulty focusing
6. Salivation increasing
7. Sweating
8. Nausea
9. Difficulty concentrating
10. Fullness of the Head
11. Blurred vision
12. Dizziness with eyes open 13. Dizziness with eyes closed 14. Vertigo
13. Stomach awareness
14. Burping

These symptoms were divided into two categories: nausea and eye movement. The score in each category is calculated by summing up the rating points of the symptoms. Example:

Subject 6: Score 'Nausea': 1 = General discomfort (1), Score 'Eye movement': 12 = Fatigue (2) + Headache (1) + Eye strain (1) + Difficulty focusing (2) + Difficulty concentrating (2) + Fullness of the Head (2) + Blurred vision (2)

The resulting total score is 13. The higher the score in the categories the higher is the appearance of the symptoms and the chance of experiencing simulator sickness (Kennedy, Lane, Berbaum, & Lilienthal, 1993).

Discussion

This paper describes what pseudokinetosis means and how the rest frame theory is related to it.

Besides the rest frame theory there are a few other theories for the virtual reality sickness. Another common theory which is also related to the behavior of the eyes is called Eye Movement theory. The Eye Movement Theory is a rarely mentioned theory that roughly says that motion sickness happens when an unnatural eye movement occurs. An unnatural eye movement is a movement of the eye, which tries to keep the image stable on the retina (Izdebs, 2018), even though a movement of the body takes place.

In medicine, adaptation of the eye to movement is also called optokinetic nystagmus (OKN). This causes so called saccades. A saccade is defined as a rapid and jerky movement of the eye, this movement fixes to focus on an object after the eye movement (Keshavarz, Riecke, Hettinger, & Campos, 2015).

Keeping the image constant occurs both in the virtual world and in the real world. An example is a train journey. If the passenger looks out of the window, an optokinetic nystagmus takes place. This process drives nerves in the brain.

This is especially true for the vagus nerve, the 10^{th} of 12 cranial nerves. It is known as the main nerve of the parasympathetic nervous system. The function of a parasympathetic nerve can be explained by ‘rest and digest’. The vagus nerve primarily regulates circulatory functions and activates the digestive function of the body. Incidentally, it stimulates the crushing reflex of the crushing center, the area postrema. Apart from the stimulation of the vomiting center, the 10th cranial nerve also controls various bodily functions, such as sweating. Like nausea, sweating is one of the symptoms of motion sickness. According to J. L. Campos and his co-workers (Keshavarz, Riecke, Hettinger, & Campos, 2015), the stimulation of the vagus nerve by eye movement is the cause of a VIMS.

We think the Rest Frame Theory is a stronger theory than the Eye Movement Theory: The Eye Movement, described by the theory should apply to everyone, everywhere traveling around with vehicles. The movement itself is just a twitch on the pupil, and if it happens to all humans. How can it get measured by whom, and is the reason for the motion sickness? The Rest Frame Theory is a more logical and measurable theory which can be verified by checking the real movement of the eye and the line of sight.

The subjects suffering from general motion sickness according to the MHQ also often suffer from pseudokinetosis. This was measured by the evaluation of the SSQ and MHQ. The subjects first filled out the MHQ right before the experiment. During the experiment they were instructed to hold on the CTRL-key if they feel any indisposition during the time in the virtual space. On completion of the experiment, the subjects received the SSQ.

Besides the SSQ there exists another Questionnaire called MSQ (Motion Sickness Questionnaire). However, for the virtual environment the SSQ is recommended (Kennedy, Lane, Berbaum, & Lilienthal, 1993).

On the basis of the heat map, we could observe a strong correlation of the eye tracking data and the answers in the SSQ.

Future Work

To minimize the occurrence of *Virtual Reality Sickness*, there are various proposals. Two of these effects are the Circle- and the Dot-Effect (Buhler, Misztal, & Schild, 2018); also see Figures 3 and 4.

The idea behind the circle effect is that the peripheral view shows the viewpoint of another camera standing still as the camera moves in virtual reality. The boundary between the outer peripheral view with the standing camera and the inner view with the image of the normal camera is visible as a circle. To limit the negative impact on the immersion of this visible artifact, the view from both cameras is mixed linearly. Once the user stops moving, the still camera view will display an updated view of the current focus perspective. During the depth motion, the peripheral camera inserts periodically updated views every five seconds so that the peripheral image matches the color and brightness levels of the focal point of the view.

Figure 3. *Dot-/ Circle Effect to Minimize Motion Sickness*

Source: (Buhler, Misztal, & Schild, 2018).

The dot effect adds artificial motion in our peripheral vision, which counteracts the virtual motion of the environment as the user moves. For example, if the user chooses to advance with the virtual reality controller at speed v, the environment appears to be moving backwards. The optical flow causes objects in the peripheral area to move away from the field of view. Such movement may cause our brain to move in the desired forward direction (called the vection). While the vestibular system contradicts this impression, the user does not really move in the real world and influences the VR disease. To neutralize this perceived movement or vection, artificial points are displayed at speed 2v in the direction of movement (see Figure 4). Relative to the user, the points appear to be moving at speed v, and the environment appears to be moving at -v. As a result, the movement of the surroundings and the movement of the points in the peripheral view cancel each other out on a zero optical flux in the peripheral vision, which then coincides with the actual movement of the user in real space.

Figure 4. *Dot-/ Circle Effect to Minimize Motion Sickness (Continued)*

Source: (Buhler, Misztal, & Schild, 2018).

Actually, we try to install an ‘early warning system’ that would classify whether symptoms of kineotosis are recognizable or not. In order to accomplish this, we will use more sensors in addition to our eye tracking system: Measurement of pulse and body temperature, the locomotion by video analysis, eventually use of EEG and our motion capture system. In order to automate this evaluation, actually, a project with a machine learning approach (especially deep learning) starts with the sensor data as input

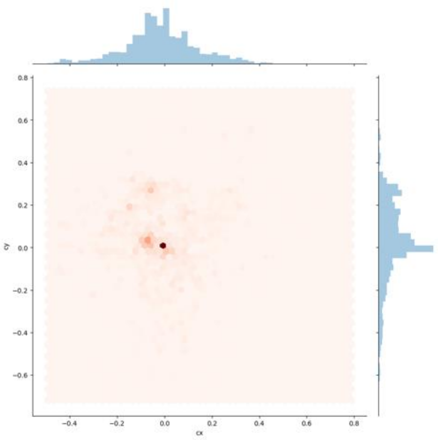
Conclusions

On the one hand our experiments show that subjects suffering from motion sickness are also often affected by the *Virtual Reality Sickness*. This is also proven by the evaluation of the SSQ.

On the other hand, the experiment analyzes the Rest Frame Theory. With the python libraries *seaborn, pandas* and *pyplot* the heatmaps of the individual subjects were generated –based on an eye tracking analysis. The dots in the pictures show that a stronger scattering of the pixels is present for affected subjects. Subjects with less (or no) symptoms have a stronger focus on one point. This leads to the assumption that is possible to analyze the occurrence of a Virtual Reality Sickness by analyzing the eye data while wearing a head mounted display.

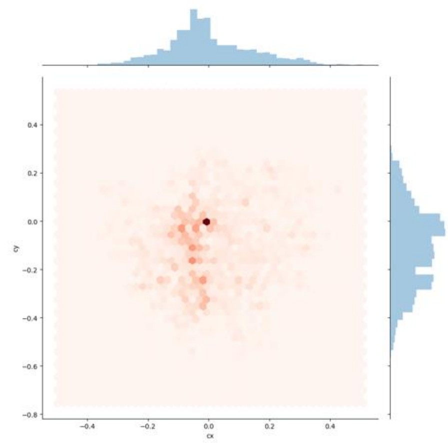
Figure 5. *Evaluation of Eye Tracking Data (Unsick)*

Subject 8



Source: CSV-File Subject 8.

Subject 17



Source: CSV-File Subject 17.

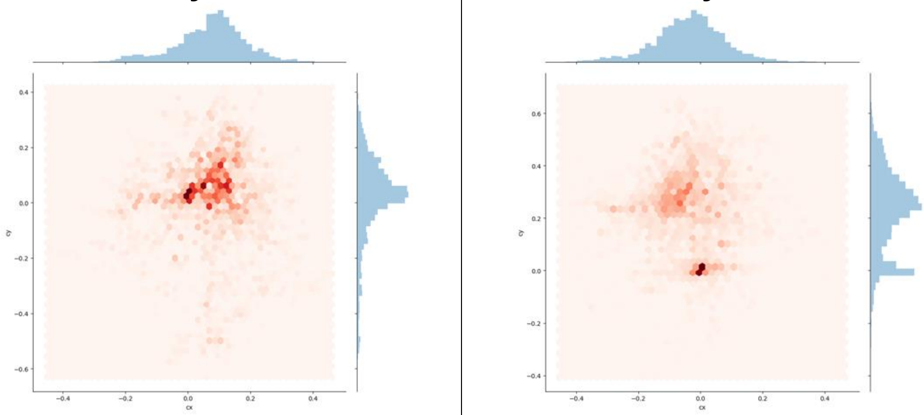
Source: Own Experiment, Seaborn Heatmaps.

We classify the subject 8 and 17 to ‘unsick’ because their eye movement field is limited to specific areas of the screen (see Figure 5). They were also strongly focused on a few specific points around their center area. They only have a few outliers, which suggest that their fix point remains.

In contrast, subjects 24 and 26 of the group ‘sick’ show that they are looking around for more than one fix point (see Figure 6). These fixed points can be seen on the heatmap. Subject 24 differs from the fix point between the range 0 to 0.2 on the cy axes. For subject 26 the fix point starts at 0 on cx axes and 0 on cy axes, outliers went down from -0.2 to 0.0 on the cx axes and to 0.2 to 0.4 on cy axes. This leads to the suggestion that subject 26 is looking for a fixed point, but he cannot receive that point.

Figure 6. *Evaluation of Eye Tracking Data (Sick)*

Subject 24 | **Subject 26**



Source: CSV-File Subject 24. | *Source:* CSV-File Subject 26.

Source: Own Experiment, Seaborn Heatmaps.

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