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A Pilot-Study into a Novel Application for Inducing and Studying Visually-Induced Motion Sickness in a VR environment.

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Figure 1: The Epley Omniax Chair [3], used for Benign Positional Paroxysmal Vertigo (BPPV) at Rigshospitalet "Center for Balance and Hearing" (CHBC) [2]. Real-time recordings are used to check the eye for nystagmus on the right in the image. This chair was used as the reference point for our VR application.

Abstract

This study presents a digital solution for inducing visually-induced motion sickness (VIMS) using a head-mounted display (HMD) in a virtual environment. By digitally replicating off vertical axis rotation by adopting the Epley Omniax Chair, we induce sensory conflicts between the visual and vestibular systems through rotational vection, alongside optokinetic stimulation inspired by the Optokinetic Drum (OKD). A secondary goal of the application is to experiment with methods for mitigating cybersickness. Self-reported data via the visual induced motion sickness questionnare (VIMSSQ) and motion sickness severity scale (MSSS) from a randomised experiment on 30 participants (10 female, 20 male) show that the application reliably induces cybersickness and can apply mitigating methods. From these findings we can confidently conclude that the application can be used as a VIMS-inducing tool.

Index Terms: Cybersickness, Epley Omniax Chair, motion sickness, Optokinetic Drum, physically-induced motion sickness, sensory conflict model, virtual reality, visually-induced motion sickness.

1 Introduction

Motion sickness and cybersickness affect people in various fields, including transportation, healthcare, and virtual reality (VR) [14]. Despite extensive research, both within the field of medicine and VR, the subjective nature of these conditions presents a significant challenge to understand and address them effectively. Both conditions share common symptoms, such as nausea, dizziness, sweating, and vertigo, but have conflicting yet similar causes. The theory of sensory conflict [19] explains the commonalities and discrepan-

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cies. According to the theory, both conditions are caused by a conflict between the visual and vestibular systems. Motion sickness, or physically-induced motion sickness, occurs when the vestibular system senses motion without the visual system sensing congruent motion. For example, this happens when riding the bus or using the Epley Omniax Chair. For cybersickness, or visually-induced motion sickness (VIMS), the conflict is caused by the visual system sensing motion without the vestibular system sensing congruent motion. This occurs in VR experiences like our product. This dichotomy between the conditions has caused difficulties in developing tools to study them and producing therapeutic or medicinal methods to prevent or alleviate the symptoms [21] [15].

This pilot-study looks into developing a novel HMD-based VR application to induce VIMS through rotational vection. The application is designed to be a cost-effective and portable solution to induce VIMS for use in clinical studies that investigate the mechanism of VIMS. Understanding the cause and effect of VIMS more thoroughly would make it easier to develop more effective treatments for the condition. In addition, the application is designed to implement visual and auditory cybersickness mitigating effects for use in studies looking at the efficacy of such effects. To investigate the application's efficiency in these two fields, we present a randomised A/B experiment using two scenarios developed for the application. Condition A involves the two scenarios without any mitigating effects, while condition B includes one of two possible mitigating effects.

2 Related Research

This pilot-study is based on the theory of sensory conflict [19], where motion sickness arises from conflicting input received by the vestibular, visual, and proprioceptive systems [22]. Thus, by stimulating one system, the mismatch between it and the remaining two systems creates a sensory conflict. Therefore, the perceptual model for the application is: by rotating the user in the virtual environment, the rotational vection created will induce a sensory conflict that produces the motion sickness symptoms.

The application developed during this pilot-study is based on two proven methods of inducing motion sickness: the Epley Omniax Chair [3], for PIMS, and the Optokinetic Drum [1], for VIMS.

2.1 Epley Omniax Chair

The Epley Omniax Chair, as seen in Figure 1, was initially designed for vestibular rehabilitation and to treat dizziness caused by otoliths in complicated cases that manual manoeuvres can not treat [3]. It can rotate the patient horizontally and vertically by turning its outer and inner rings. This rotation utilises gravity to reposition the displaced otoliths in the inner ear's three semicircular canals.

The Epley Omniax Chair can be used to induce PIMS by using off-vertical-axis rotation [7]. The subject is securely fastened in the chair before being rotated 360 degrees around the chair's axis. Through repeated rotation, it has shown itself to be able to induce PIMS in the subjects in a standardised experiment setup.

2.2 Optokinetic Drum

The Optokinetic Drum (OKD) is a cylinder with horizontal black and white stripes made to be spun around. While the OKD is rotating, the movement of the striped pattern creates rotational vection in the subject, generating a visual-vestibular conflict causing VIMS [5].

The OKD has two design variations: a handheld version and a room-scale version, as shown in Figure 2. The room-scale OKD is what we base one of our two scenarios on, as can be seen in Figure 3.

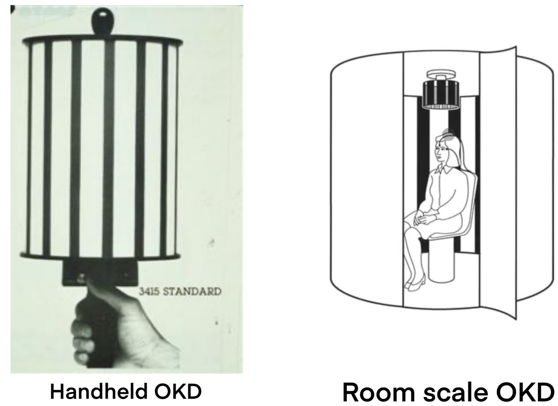

Figure 2: Handheld (left) and room-scale OKD (right) [1]. The handheld OKD is held in front of the subject when it is spinning, while the subject sits inside the room-scale OKD while the outer drum spins. The room-scale OKD is what we base the application and pilot-study on.

2.3 Cybersickness Mitigating Effects

To test the full scope of the application, we wanted to experiment with implementing proven methods for mitigating the effects of cybersickness. For our experiment, we implemented visual guides based on the work done by Seok KH et al. [24]. In the cited research it was found that combining a size of 30% of the screen resolution and HMD head tracking positioning was the most effective at reducing cybersickness. Both the sizes of 10% and 50% were less effective than 30% but were equally as effective as each other. Using virtual movement-based positioning had no positive effect on cybersickness, and using both HMD head tracking and virtual movement-based positioning had a worse effect than just using HMD head tracking. We also implemented stereophonic white noise as an audio-based mitigating method. This method was not based on prior research, which we will detail more in section 7.

3 Development

The application was developed using Unity version 2022.3.46f1. To ensure that the hardware had minimal interference with the experiments, we designed it for Meta's higher-end commercial HMD, the Meta Quest Pro. The application was designed to be a functional digital recreation of the Epley Omniax Chair [3].

The application's key features are the two scenarios and the X- and Y-axis rotational capabilities. The first scenario is based on the room-scale OKD, wherein the subject is placed within the virtual drum (see figure 3). The second scenario is based on overstimulating the subject's visual sensors with colour and movement, alongside the rotational vection. This is done by placing various spheres around the virtual environment with randomised colors and randomised animations (see Figure 4). The X- and Y-axis rotation is based on the horizontal and vertical rotation that the Epley Omniax Chair is capable of.

3.1 Development Process

The development process also included a preliminary testing phase to narrow down the available options to two final scenarios. These options and the final version of each scenario are described in the following sections. These preliminary tests were conducted over two sessions, focusing on one scenario in each session. Each session included 5 participants who were exposed to each variation of

Figure 3: The OKD recreation with a visible Epley Omniax Chair, as seen by the Unity inspector. This scenario is based on the room scale OKD seen in figure 2. The subject is completely surrounded by the drum, leaving only the material on the inside visible. The material uses a noise-generated pattern and changes its colours based on a predefined gradient. The chair was not visible to the subject during the final experiment.

the scenario. They were then asked to rank them among each other according to their level of discomfort when exposed to the variation. They were asked to rank the variations from 1 to 4, with 1 being the most discomfort-inducing and 4 being the least. The rank was then used to tally the variations' scores. The highest ranking variation was given a score of 4, with the lowest scoring getting a score of 1. The highest-scoring variations were then selected for the final experiment.

3.2 Scenario 1: OKD Recreation

For the OKD recreation, we used Unity's shader graph system to develop 4 different patterns for the drum's interior. The patterns we made were the following:

- Black and white stripes, similar to the actual OKD.
- Generated black and white noise pattern with a shifting pattern.
- Generated coloured noise pattern with shifting colours.
- Generated coloured Voronoi noise pattern, with shifting colours and pattern.

From these patterns, we found the coloured noise-generated pattern with shifting colours ranked the highest. The final version can be seen in figure 3.

3.3 Scenario 2: Sphere Scenario

For the sphere scenario, we utilised preliminary testing to see whether the spread of the spheres affected the subjects and whether the animations were effective at improving our VIMS induction. Thus, the variations we tested were the following:

- No animation and with the spheres spread over a large area.
- No animation and with the spheres spread over a small area.
- With animation and the spheres spread out over a large area.
- With animation and the spheres spread out over a small area.

Among them, we found that the animations significantly negatively impacted the subjects' discomfort. The spheres being spread over a small area also had an effect, but anecdotally, not as severe. This means that the variation with animation and the spheres spread out over a small area was a clear candidate for the final experiment. The final version can be seen in figure 4.

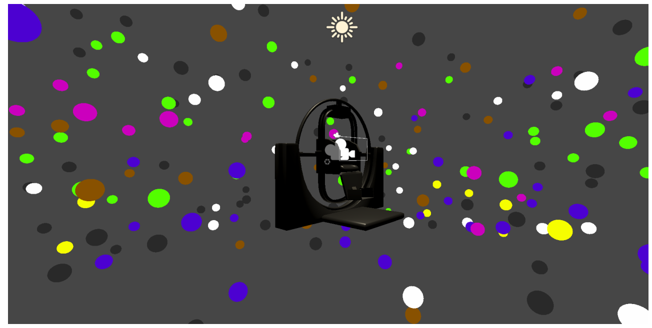

Figure 4: The sphere scenario with a visible Epley Omniax Chair, as seen from the Unity inspector. The spheres have randomly assigned colours and animations. The animations have 9 horizontal, vertical, and diagonal variations. The chair was not visible to the subject during the final experiment.

3.4 Auditory Effects

Additionally, we wanted to experiment with using audio techniques as another avenue for reducing cybersickness [23]. We used the same setup for the preliminary test of the audio variations. Each audio variation was implemented in the OKD recreation scenario, and like before, each participant ranked them after being exposed to each of them. The audio variations were the following:

- Spatialized white noise, with a source directly in front of the starting position.
- Monophonic white noise.
- Stereophonic recording of the Epley Omniax Chair in motion.
- No sound.

The reasons for using these effects were varied. For spatialised white noise, we operated under the assumption that the spatial cue the audio created for the user would reduce discomfort. However, we found that it had the opposite effect, which is supported by findings by Keshavarz et al. [17] and Dicke et al. [8]. The monophonic white noise was chosen as a neutral noise option with no directional cues. The stereophonic recording was used as an anticipatory audio cue based on work by Kuiper et al. [20].

Among these, we found that monophonic white noise had the most significant effect on reducing discomfort.

4 Methodology

We assessed the application's efficacy using a randomised A/B experiment structure with a within-subject approach. The A/B structure was used to compare two conditions: the presence or absence of a visual guide and the presence or absence of sound in the virtual environment. Through convenience sampling subjects were selected: Of the 30 participants included in the pilot-study, 10 were female, aged 23.2 ± 2.2 years (19 to 26), and 20 were male, aged 23.75 ± 2.71 years (20 to 31). They were divided equally between the two conditions, with 15 in each. The subjects were exposed to the two scenarios without any mitigating methods; 15 were exposed to the scenarios with the visual guide added, and 15 were exposed to the scenarios with audio added. The experiment protocol is visualised in figure 5. Each subject was informed verbally and in writing about the purpose of and potential risks involved in the experiment. They gave written consent to participate in the experiment and were rewarded with a movie ticket. Approval from the Danish National Committee on Health Research Ethics was obtained for this pilot-study.

We used a mixed-method approach for data collection, with two questionnaires for quantitative data with qualitative observations. The questionnaires used were the Visually-Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ) [18], to ascertain the subject's experience with and susceptibility for VIMS, and the Motion Sickness Severity Scale (MSSS) [6], for the subjects to rate their discomfort and nausea before and after the experiment. Both questionnaires are commonly used and proven methods for assessing motion sickness in clinical studies [16] [15]. The questionnaires were given on paper to each subject before the experiment began, with a short verbal explanation.

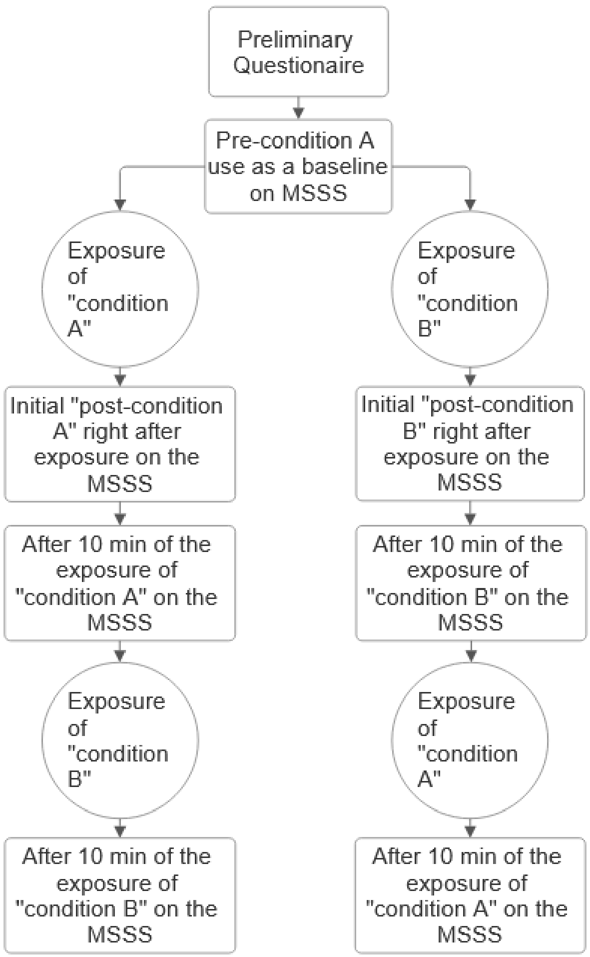

Figure 5: Flow chart of the experiment protocol.

4.1 Results

We found that the mean MSSS score for post-exposure to condition A for all 30 subjects was 1.433 with a standard deviation of 1.135. The mean MSSS score for the 15 subjects post-exposure to condition B in the scenario using the visual guide was 0.466, with a standard deviation of 0.743. The mean MSSS score for the 15 subjects post-exposure to condition B with the scenario using audio was 1.533 with a standard deviation of 0.915 (see table 1 and table 2).

To analyse the data, we used the non-parametric Wilcoxon single-rank test to compare the MSSS scores between conditions A and B for each scenario (visual and auditory). The mitigation scenario in the Visual scenario significantly decreases motion sickness (p = 0.034). In contrast, the auditory scenario showed no signs of mitigating any motion sickness (p = 0.655).

Using the Pearson correlation coefficient, we found no correlation between the VIMSSQ and the MSSS scores (r = 0.1179 & p = 0.534932).

Statistic	AGE	VIMSSQ	MSSS_PRE
Mean	23.6	24.6	0
Std. Deviation	2.5	19.0	0
Minimum	19	3	0
Maximum	31	84.3	0

Table 1: Summary statistics for AGE, VIMSSQ, and MSSS_PRE

Statistic	MSSS_POST_1	MSSS_POST_2	MSSS_POST_3
Mean	1.17	1.26	0.6
Std. Deviation	0.91	1.23	1.13
Minimum	0	0	0
Maximum	4	3	4

Table 2: Summary statistics for MSSS_POST variables. MSSS_POST_1 is the MSSS score immediately after being exposed to condition A. MSSS_POST_2 is the MSSS score immediately after being exposed to condition B. MSSS_POST_3 is the MSSS score immediately after having been exposed to both conditions.

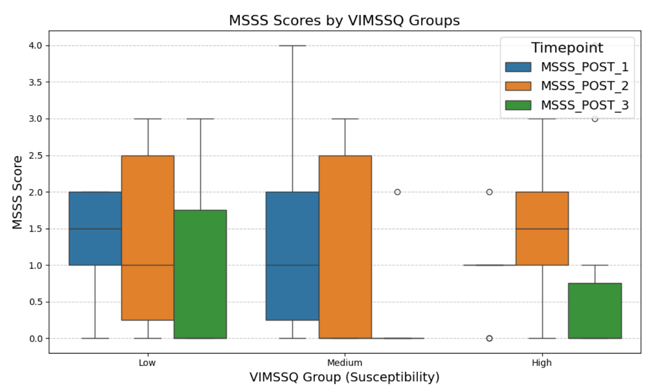

Figure 6: The VIMSSQ scores were divided into three groups and compared to MSSS scores.

We applied the Mann-Whitney U-test to see if the two independent groups, male and female, differed in their distributions of VIMSSQ and MSSS POST scores. The analysis for males during the early stage (POST_1) showed that gender did not significantly affect the MSSS scores. However, in the later stages (POST_2 and POST_3), gender became a significant factor, suggesting variations in the responses to motion sickness with females being more affected in the later stages (POST_2 and POST_3) See figure 7.

5 Discussion

Our data suggests that the application was effective and reliable at inducing VIMS in subjects, supporting its usability as a VIMS tool for clinical experiments. Additionally, we found that the visual guides could reliably reduce the discomfort in the subjects, which supports the findings of Seok KH et al. [24], lending some credibility to the application's use to test visual mitigation effects. The results also show a clear trend that the female subjects we tested on on average had it worse than the males. Females reported higher MSSS scores compared to males during both MSSS_POST_2 and

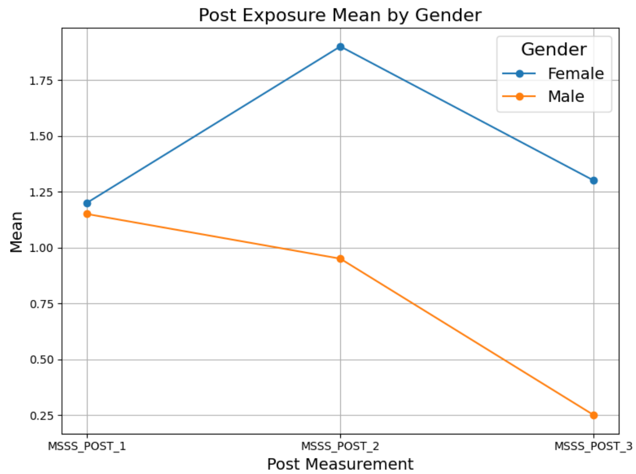

Figure 7: Post-exposure mean by gender.

MSSS_POST_3. In post 2, females reported a median score of 2, while the median score of men was 0.5. This disparity suggests that females may be more susceptible to motion sickness in our VR environment. Existing research shows that gender does play a role in motion sickness susceptibility. Research suggests that women are generally more prone to both PIMS and VIMS. A key factor here is the inter-pupilary distance (IPD), which is typically smaller in women compared to men. The IPD have not been changed on the HMD since it was bought and it was initially fitted to a man [13] [10]. This congruency with established data lends credence to the application VIMS-induction capabilities.

However, due to the subjective nature of motion sickness our data collection methods had limited potential. The VIMSSQ and MSSS were found to be unreliable to use as our primary data collection method. We found no correlation between the VIMSSQ scores and the MSSS scores of the subjects, and the standard deviation of the MSSS scores was higher than anticipated. This might indicate that these questionnaires are better suited to complement biometric sensors that measure galvanic skin response, heart rate variability, and eye tracking.

Furthermore, our convenience sampling could have introduces some bises. Mainly in the form of sampling bias and social bias. The sampling bias comes from us primarily finding our participants on the AAU Copenhagen campus, where a larger part of the population has experience with VR applications. This experience could led to a lower susceptibility to VIMS [9]. The social bias was introduced in how we conducted the experiment. To save time, we introduced the experiment to our participants in pairs, and performed the experiment sequentially. This setup could introduce the social bias whenever the two participants knew each other. This was most notable when two male participants knew each other. We observed some bragging and showboating going on between each testing phase, which might have led them to downplay their symptoms to seem more robust than the other.

Additionally, we could not validate whether the audio effects have a mitigating effect. This is likely due to the efficacy of the effect itself, but further research is needed to confirm whether the effect was inefficient or whether the application is inappropriate for testing auditory effects.

6 Conclusion

During this project, we developed and tested a VR application with the primary goal of inducing VIMS and the secondary goal of being able to experiment with different cybersickness mitigating methods. The application is based on the PIMS induction experiments conducted with the Epley Omniax Chair and the VIMS-inducing OKD. The base perceptual model for the VIMS induction is as follows: by rotating the user in the virtual environment, the rotational vection created will induce a sensory conflict that elicits the motion sickness symptoms. Experimental validation confirms that the application can reliably induce VIMS in the subject and that the visual guides implemented could reliably mitigate the symptoms. The experiment could not sufficiently validate whether the audio scenario mitigated the condition, so further examination is needed to confirm that the application can reliably test every cybersickness mitigating method. Further investigation should be conducted to verify whether the success of the visual guides can be extrapolated onto other visual cybersickness mitigating methods. Furthermore, additional experimentation should be conducted using sound as a mitigating method to verify whether it has any impact.

Our findings indicate that this application is a successful foundation for a standardised virtual VIMS-inducing tool. The application also shows potential in its cost-effectiveness compared to the room-scale OKD. Both the cost of hardware and installation largely outweighs the cost of the HMD the application requires. With additional improvement in the areas of usability, biometric sensing, and technical implementation, the application can open up for more thorough research in the field of VIMS and its connection to PIMS.

6.1 Future Works

Looking forward, we plan to implement a series of improvements to the application based on the success of the VIMS induction and the success of the visual guides. Furthermore, we plan to adjust our preliminary testing- and experimentation methodology and reevaluate the sound-based cybersickness mitigating methods.

6.1.1 Additional Implementation

This section of future works focuses on improving the application of clinical experimentation by making it easier for the researcher to work with it. By implementing a user interface that was accessible from outside the HMD (i.e., from a computer), the researcher would be able to control the rotation of the subject remotely and adjust any variables (such as rotational velocity). This interface would also allow the researcher to see the virtual environment, allowing them to monitor the experiment more precisely. Furthermore, we plan to implement eye tracking as a way to detect any potential nystagmus [4] and would allow the researcher to monitor whether or not the subject was closing their eyes for any prolonged period. The interface mentioned earlier would then allow the researcher to access the eye-tracking data and view it in real-time.

Another aspect we would like to expand upon, is the cybersickness reducing methods available. By implementing eye tracking, we unlock a new avenue of more sophisticated methods. These methods could include the two types of peripheral distortion explored by Groth et al. [12] [11]: peripheral blurring [12] and peripheral distortion [11]. These methods could be used to test the application's usability further in verifying visual cybersickness reduction methods.

6.1.2 Adjustments

This section of future works focuses on the adjustments we believe should be made to the methodology of this study in the future. Our final experiment was marred by us wanting it to be quick to make it easier for us to find willing participants. By going beyond convenience sampling and plan around having the subjects show up on predetermined days, we could find more participants that would be willing to spend more time on a more extended experiment. This would allow us to use additional data collection methods, such as the Fast Motion Sickness Scale [16], that require a larger time frame.

Also, our data suggests that female participants were substantially more susceptible to VIMS. This is congruent with other studies that have been done [25]. This would suggest we should have a more equal distribution of female to male participants to have a more complete data set on the VIMS induction.

Another experiment parameter we would expand upon is the usage of physiological measuring. As mentioned earlier in section 5, we believe that our data collection methods would have been improved if they were supported by biometric data, such as galvanic skin response, heart rate variability, and eye tracking.

Finally, we should reevaluate our preliminary experiment method and the results we got from them. The preliminary experiment method was not thought out well enough and was conducted on a sample size that was too low. The test was conducted to reduce the number of variations we were going to test. We should experiment rigorously with each current and future variation. However, we must reevaluate the scoring system, reduce potential biases, and expand the sample size.

7 Limitations

During this study, we implemented monophonic white noise as another cybersickness reducing method. The choice to implement this was made rather late in the implementation phase. This led to our research into previous proven auditory methods to be lacking. In retrospect, basing our audio on the auditory distractors explored by Venkatakrishnan et al. [26] would have been ideal. Our methodology for choosing the audio type can also be blamed for the poor audio effect.

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