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Impact of Delay in Virtual Reality Cloud Gaming

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OSLOMET

Preface

This thesis aims to answer some questions in virtual reality experiences. The choice of topic comes from authors personal interest in gaming and user experience.

I would like to thank my supervisors for their immense support and the collaborating institution for offering their facilities to conduct the user testing.

M. Qasim, August 2022.

Abstract

This thesis investigates the impact of delay in virtual reality gameplay. 32 participants play a squash game in a user study and rate their experience in addition to answering questionnaires. We found out that delay is noticeable even at lower value of 20ms and from here on, the experience worsens and eventually is reported to be fully unstable as we move up on the scale all the way to 120ms. We also touched on some of the differences in personal factors concerning the participants, such as gender and experience. We found out that participants who are male and/or have higher level of experience are more likely to report delay at a lower value. This study shows that any future work in this area should also consider more instances of delay with lower value and game developers should try to eradicate any or higher level of delay to provide an optimal gaming experience.

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Introduction

Gaming industry is huge with combine sales of more than hundred billion dollars across platforms (Statistica). Some gaming titles have frequently exceeded Hollywood blockbusters in earnings. Games are also big part of everyday life and society, chances are that most or many have played games at least once.

Cloud gaming is gaining traction as the next big thing in the industry. Cloud gaming as the name suggests, games are run off of cloud servers instead of it being run on local hardware. Users can either subscribe to dedicated cloud-based gaming services or can lease compute power with storage and install the games they own.

Cloud gaming carries many benefits over now (potentially) legacy localized gaming. By far the biggest benefits are low cost and portability. In order to run games in high fidelity, decent hardware is required and it may cost allot. Cloud based gaming may potentially offer same level of high-fidelity experience at fraction of a cost. Additionally, savings can be made on power bills and hardware failure risk is eliminated.

Cloud gaming is by design free of any hurdles of portability. As long as there is good network access, it can be accessed anywhere and on almost any hardware form factor.

Cloud-based VR gaming is another advancement in this field and it takes cloud gaming to the next level. It brings in high level immersion in addition to the graphical fidelity.

Cloud gaming also brings some challenges; biggest being latency in network. Network connection can make or break the experience of cloud gaming. Any latency, packet loss can affect gameplay bigtime, especially for latency sensitive genres like first person shooters. It is therefore critical that the network connection is stable.

Cloud gaming in virtual reality is even more delay sensitive and implications are far worse than regular 2d displays. Any delay in network and subsequent delayed registration of action on screen with motion of body or controllers can bring in high risk of getting motion sickness.

Research questions

In this thesis we will try to find an answer for the following questions:

1. Impact of delay in virtual reality on gameplay experience
2. Impact of difference in genders on perceiving the influence of delay
3. Impact of prior experience with virtual reality on sensing the delay
4. Impact of low or high tolerance to delay and it's effects?

Ethical considerations

The user testing has no issues related to personal data as no identifying information is collected however it brings some other ethical issues.

Since the study is about delay in VR and as mentioned earlier, any or higher level of delay can cause motion sickness. Not everyone suffers from same level of motion sickness as people have different tolerance levels to it but there is high probability and majority does feel it to some extent.

This was quickly learned with pretesting when there were several high-level states of delay. 3 out of 4 participants experienced immediate and high levels of motion sickness. They described the experience as highly nauseating. In light of their feedback, some high-level states of delay were removed for main study. Now the participants still experience motion sickness but it is more tolerable and only worsens by the very end of a test session.

Another issue is proper positioning of VR headset; It is critical that VR headset and the lenses inside are positioned right in front of the centre of eyes, otherwise images projected may be blurry, glary or with ghosting. Additionally, some users wore correction lenses/glasses and that brings another challenge. If the image is blurry in VR it can cause motion sickness with prolonged usage. It was critical that I made sure that users find ideal position for headset. Vive pro 2 offers several adjustments; like rotary dial at the back of head to tighten and minimize movement of headset, an optional spacer so that it can be worn with prescription glasses, lens IPD (Inter Pupillary Distance) correction and lateral lens spacing. It takes a while and lots of feedback from the user to find the correct position but it is absolutely critical not only to prevent motion sickness but for also making the tests more enjoyable.

Above all, it is critical that to ensure transparency, users are briefed about the potential of motion sickness, especially to the particpants who experience it in other ways like while being driven. There are ways to minimize or suppress the motion sickness by for example slightly closing the eyes and minimizing the movement of head. Users should not feel pressured to conclude the test and can stop it if they don't feel like continuing it. Participants should have full understanding before going for the test.

Contributions

A paper was co-authored and was accepted in a conference during the time this thesis was being written:

"When Every Millisecond Counts: The Impact of Delay in VR Gaming" @ 2022 14th International Conference on Quality of Multimedia Experience (QoMEX)

The paper was well received by the community.

Related work

Immersive virtual reality (IVR) allows the user to enter a virtual world and experience a close to reality involvement. However, as soon as the user experience delay, meaning their movement does not match what they see, the user experience is highly impaired. Caserman et al. carried out a study with the objective to gain insight into such latency (Caserman et al, 2022). By analysing and tracking cybersickness, time it takes for a user to reach a set target and sense of body ownership they found various interesting results. Their study indicates that latency above 63 ms induces cybersickness and user performance decreases drastically at a latency above 69. Conversely, body ownership is first affected at a latency above 101 ms, and significant impairment were not discovered until a latency of 192 ms. The study concludes that latency between physical movement and what the used see does not induce a very significant level of cybersickness but does impair user performance and sense of body ownership (Caserman et al, 2022).

As the popularity of computer games rises, game providers are constantly working on enhancing the user experience for their games. This can be done by developing a high-performance platform, new interaction techniques and by rolling out new types of games and variations. However, it is not always clear how these developments effect the user-perceived Quality of Experience (QoE).

In the article "Gaming taxonomy: An overview of concepts and evaluation methods for computer gaming QoE" (2013) Sebastian Möller, Steven Schmidt, Justus Beyer provide an insight into computer gaming evaluations and understanding from the point of view of a quality engineer. The authors differentiate between three types of QoE, namely influence factors on QoE, performance aspects and quality features (Möller et al, 2013). Their findings can be applied in the future development of empirical test methods and in prediction models for computer gaming QoE (Möller et al, 2013).

Mobile gaming is the largest gaming area in the world, and the market is increasing. The category with the currently fastest growth is the interactive mobile games, where Quality of Experience (QoE) is crucial. However, the QoE can be influenced by degradations such as delay and packet loss. Game providers must therefore make sure that the connection between the server and the users are quick and reliable. For this process to run smoothly, QoE prediction models are essential. Schmidt et al. investigates a thorough parameter space containing several conditions of delay and packet loss, with the objective to develop an efficient model for securing QoE in Online Mobile Gaming (OMG). The experiments conducted were on delay and packet loss connections in the game Fortnite. The goal of this study was conducted to investigate if a model of Cloud Gaming (CG) could be used for OMG, to narrow down the testing for a more accurate model and to find the most suitable quality features for gaming QoE. This study found that the consequence of delay is far greater in CG service than in OMG service. In conclusion, a different model for OMG QoE would be necessary. The analyses also provide information on how to create such new model, by selecting a proper parameter space, meaning the combinations and levels of packet loss rates and delay (Zadtootaghaj et al, 2021). Zadtootaghaj et al. also propose a method that uses a high SLP and jitter probability to their corresponding delay and packet loss rates. This method would be used to simulate realistic network conditions (Zadtootaghaj et al, 2021). The paper concludes that network delays characterize a more severe impairment than packet loss. Furthermore, Online Mobile Gaming is less prone to issues relating to network than Cloud Gaming.

The Oculus Rift is claiming to revolutionize gaming experience. In their article “Exploring Gameplay Experiences on the Oculus Rift” (2015) Chek Tien Tan, Tuck Wah Leong, Songjia Shen, Christopher Dubravs, Chen Si investigate this VR system and explore the experience users encounter when using the Rift playing games. Getting to know the nature of user experience while playing on the Rift would provide a deeper understanding that can be applied when developing new experiences for the Rift.

The study conducted included 10 participants playing a first-person shooter game, Half-Life 2. Both qualitative and quantitative data were collected, while the participants played the game on both the Rift and on a desktop computer. Data collected consisted of physiological data, recordings of gameplay as well as observational data, recordings of think-aloud sessions conducted afterwards, semi-structured post-game interviews, scores for Flow and Immersion through questionnaires and Immersive experience questionnaires (IEQ) (Tan et al, 2015). Despite experiencing cybersickness and a lack of control, the participants in the study reported better experiences, more engagement with passive game elements, as well as a higher level of flow and deeper immersion when playing on the Rift and on a traditional computer. The article concludes by providing guidelines for future game designing for the Rift. They recommend that one must recognize the power of heightened intensities, as games tend to be more intense in the Rift than on a traditional computer. Furthermore, they advice to be conscious of the different interaction times and their limits, considering that certain interaction types enhance the experience on the Rift while others do the opposite. Additionally, they urge the consideration of time to familiarize oneself with the device, as well as the importance of rethinking design and role of passive elements. Lastly, they recommend the inclusion of cybersickness in the design process, as this is a common reaction to VR (Tan et al, 2015).

Cloud Gaming is increasingly popular, and the service require a vastly reliable network and the latency must be very low for the Quality of Experience (QoE) of the users to be satisfactory. High levels of latency could cause a great deal of frustration for the user. However, in their article “Delay Sensitivity Classification of Cloud Gaming Content” (2020) Sabet et al. find that the negative outcome of latency would to a high degree depend on the content of the game. A shooting game for example would be highly impaired by delay, while a slow-paced game wouldn’t be as affected. Sabet et al argue the importance of considering this factor when developing cloud-based games, and their research contribute to an enhanced understanding of latency and its impact on QoE. Furthermore, the article presents a highly accurate evaluation methodology to quantify game characteristics that influence the user’s latency perception.

In their article “GENERALIZEABILITY OF LATENCY DETECTION IN A VARIETY OF VIRTUAL ENVIRONMENTS” (2004) Stephen R. Ellis, Katerina Mania, Bernard D. Adelstein, Michael I. Hill study perceived sensitivity to changes of system latency. This was tested in three different virtual settings. The first had one foreground object, the second had one background object while the third had both a foreground and a background object. They found that perceived stability requires a latency of less than 16 ms.

Latency in virtual reality tends to impair user performance and Quality of Experience and induce motion sickness. However, when tested, participants are typically healthy young individuals. In their article “Head Tracking Latency in Virtual Environments Revisited: Do Users with Multiple Sclerosis Notice Latency Less?” Gayani Samaraweera, Rongkai Guo, and

John Quarles investigate how latency effects mobility impaired (MI) participants in comparison to healthy participants. The study was conducted similarly as earlier studies, and the results show significant difference between the participants with mobility impairment and the heathy ones. The MI participant showed a significantly lower sensitivity to latency than the healthy participants.

S. Weech et al. (2019) in their review article 'Presence and Cybersickness in Virtual Reality are Negatively Related' give some insights into this complex relationship between cybersickness and presence in a virtual reality environment. There may be a connection between the observer's sense of presence and the sensation of physical pain in virtual reality, however, the literature on this subject is scarce. But it is also important to understand the desired impression of "presence" in a virtual place and how to reduce the unpleasant sensation of "cybersickness". The current review also points out one area where our knowledge is lacking, specifically how experimentally altered sensory mismatch affects presence. Future work will need to find ways to manipulate and evaluate sensory mismatch in empirical research due to its potential modulatory effect on the association between presence and CS.

The processing and rendering capabilities of VR systems have significantly improved in recent years, however, there are fewer problems to comprehend and difficulties to overcome. K. Raaen et al (2019) in their study on temporal constraints on VR show how subjective experiences vary between individuals with different attributes. To demonstrate this, he allows players to control the amount of delay in a game and feel both the immediate short-term consequences and the possible long-term effects in a VR interactive environment. This demonstration accomplishes two goals. One, it offers a player to experience VR delays directly, and secondly, this acts as an experimental setting for ongoing research into the limitations and effects of delayed VR interactions.

T. Waltemate et al. (2016) in their study assess the psychophysical performance with a concentration on more complicated movements involving the full upper body, as opposed to other research that mainly focused on manual tasks in a VR setup by producing the delays between 45ms and 350ms. Results showed that extending the delay from 45 to 75 ms had no noticeable effects on participants' performance, but gradually increasing the delay above

75ms affected participants' perceptual judgments. Sense of body ownership also considerably start declining between 125ms and 210ms.

To measure small latencies in a VR environment, S. Kawamura et al (2016) investigated the human equilibrium and HMD’s latency with the subject experiment and found a very interesting relationship between them. The experiment's latencies varied from 1ms to 66ms. The subject's balance steadily declined as the latency grew and it is directly related to the high-quality HMD, field of view, and resolution of VR.

E. Kokkinara et al .(2015) presented a unique concept where the body and its movements may be controlled and seen as a whole in a fully virtual world. As VR technology is growing rapidly and seen as the most widely used technology in the future, unconscious adaptation to visibly altered movements may be useful in VR applications. For instance, one can present in a virtual world while being in a small, confined space and such results can be very useful for future behavioral studies that lead to more adaptive practical applications for the VR environment.

To see the effects of end-to-end latency on a person’s performance in a virtual environment, A. H. Morice et al (2008) did a virtual ball-bouncing task as a paradigmatic example to study the action-perception patterns. The results from these psychophysical ball experiments show that even with the minute changes in the end-to-end latency (ETEL), the action-perception behavior of the subject is disturbed and these findings demand to include action-perception factors for evaluating the accuracy of VE systems.

K. Raaen et al (2022) found ways to detect delays in instant and quicker movements as the results from measuring delay for these abrupt movements are more in line with users' sensitivity. The setup they used for such measurements didn’t require any modification or alteration to the VR system and it allowed them to get the desired values as well. The acceptable delay on which both developer standards and scientific articles generally agree is less than 20ms. In light of this, it is apparent that the phones are operating too slowly even the latest models of iPhones are not compatible to run VR systems however, Samsung S5 is closer to acceptable as it gives a lower latency value compared to other phones of this year model. Samsung phones claiming VR devices like Note 4 and Note 5 are the only devices working with Gear VR. Oculus Rift solely made for the VR environment is incredibly fast as compared to the phones and satisfies the guidelines as well.

S. S. Sabet et al (2020) in their article discusses the challenges in cloud gaming and how the transmission latency lowers the quality of the experience for consumers. In that paper, they proposed a latency compensation method that uses game adaptation to lessen the impact of delay on quality of experience (QoE). The proposed technique used the five characteristics for the adaptation along with the aim-assistance method. Four games were used with 194 individuals to evaluate those characteristics for this experiment and that was carried out with the help of a crowdsourcing approach. The users reported significant improvement in quality of experience (QoE) and spatial accuracy, temporal accuracy, and predictability were the most efficient in mitigating the delay.

Methodology

A user study is conducted; users will play a game developed for this in VR and delay will be simulated. They will answer a question during the test (repeated multiple times), answer a questionnaire before the test and one after the test.

Hardware

The VR hardware we are using for the test is HTC Vive Pro 2; this VR system is one the best consumer grade VR system commercially available in the market. The screens are high resolution and it overall provides an immersive experience.

A wireless module is also attached to the system. This eliminates the requirement of a wired connection to the PC it runs off of. Wireless connection enables more free movement and reduces the risk of tripping over the wires or accidental disconnection. In my experience; while testing, the connection was stable and provided a smooth lag (network) free experience. One downside being that it adds a little weight to the system.

Spot camera tracking was also available; this helps with tracking of gestures and movement with higher level of accuracy, bringing in even more immersion. With the help of spot camera tracking; system provides a more defined play area and gives better understanding of the limits. Virtual walls appears inside the VR environment; when a user nears this wall or breaches it, smart interactive animations appear to warn the user. This reduces the risk of exiting the safe area and running into objects in real life.

These high end VR systems require a computer source for their operation; in this case a high end system with following key specs:

- Intel Core i9 9900k
- 16 GB dual channel memory
- Nvidia RTX 3070
- High speed storage, high end motherboard board and a high-resolution display output

Host systems specification have big impact on the output resolution, frame rate and overall general smoothness of gameplay on the VR. This system provides all of that with some margin.

The game:

A game was developed from the ground up for tests like these.

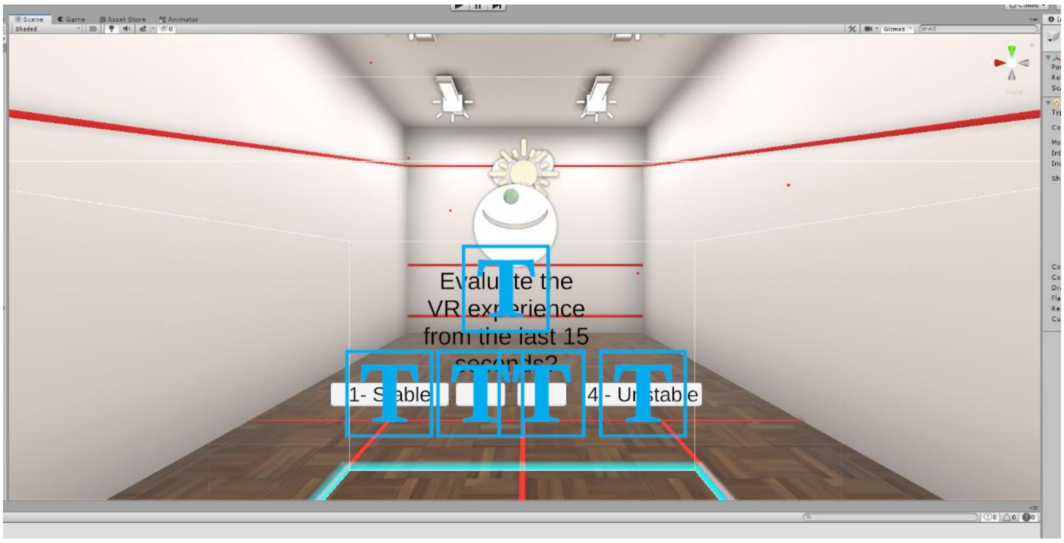

Figure 1 Squash game in unity

The game is a squash game with quite a simple set design built for the purpose of testing rather than high fidelity experience. The game has fairly accurate physics; the gestures accurately corresponds to the movement in VR and response has natural feeling to it. Since it is squash; it requires use of only one hand to move the racket to hit the ball.

This game is ideal for tests like these; since there was limited but reasonable available space, this game can be played easily without much of a requirement of moving or running to different spots. Users can easily reach over with their hand for the ball. The game was engaging and users had fun playing it.

The test:

The test emulates delay artificially; this meaning it is neither network based, nor input based. The delay is basically between the time when a user performs a gesture and when it is registered as an action. Users have the feeling of disconnect and the physics which are not normal at all.

Figure 2 Participants in a test session

For example, to hit the ball, user swings their arm in the general direction of where the ball is present according to their assessment and intuition. The resulting gesture might be right on the target but there is a high chance that due to this artificially and purposefully introduced delay, the racket (virtual) will completely or partially miss the desired target point, thus resulting in unsuccessful or incorrect return of the ball. We will discuss in detail how this impacts the quality of experience later with the results but to put it briefly this scenario is undesirable, disengaging, frustrating, unenjoyable and may also lead to motion sickness.

Delay:

The introduction of delay is randomized instead of it being gradual-linear. The Reason for this is that, if users have this understanding of the fact that the delay will gradually increase during their gameplay session or there is this probability that they will be judge that the increase is gradual and then most of the answers about their experience of gameplay may be linear, repetitive, identical and predictive. Hence it was decided that the introduction of delay should be randomized and even when they are briefed about this and they have this information prior to the test they will likely be more attentive to the experience they are having and the answers they are providing.

So, a test session may begin with high state of delay or none or something in between. Change in delay state is introduced on an interval of every 15 seconds. After that (15th second) a prompt appears on the screen asking the participants to rate their experience from the last 15 seconds.

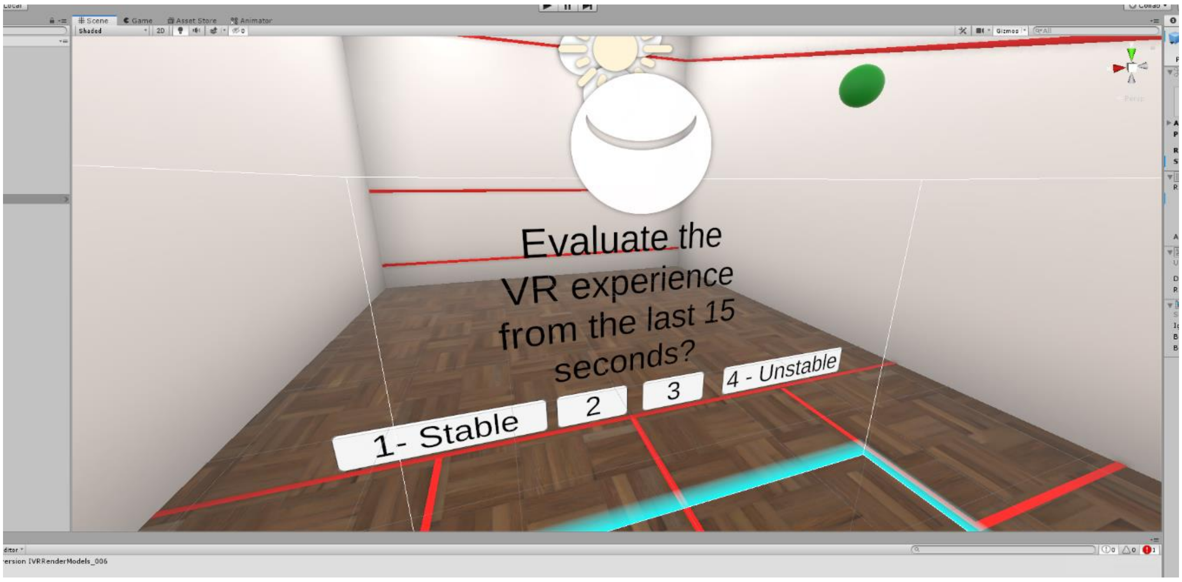

Figure 3 Game in unity

Users are presented with 4 different options:

Table 1 Questions and answers from the prompt

Please describe your experience from past 15 seconds			
1:Stable	2:	3:	4:Unstable

Each state of delay is repeated twice and the session ends with appearance of all states. On average, one session lasts around 3 minutes and can be shorter or longer depending on how quickly user answers and dismisses the prompt.

Pre-tests and setting up the scenario:

The main user test was fine-tuned by conducting pre-tests with four participants. Initially, there were more states with high levels of delay and a single session lasted longer. Changes were made for the final user study and we settled on following:

Delay states:

Table 2 Delay states

#	Delay (in milliseconds)
1	0
2	20
3	50
4	80
5	120

Interval: 15 seconds
Repetition: twice

Results from one of the pretests: (1 user, 1 session)

Table 3 Results from a pretest

Round count	Response	Delay state	Duration	Frames
1	2	5	22.68727	2042
2	1	0	20.52924	1848
3	3	8	25.35748	2284
4	1	0	20.0811	1808
5	3	8	17.61938	1587
6	2	5	39.84428	3586
7	4	12	20.754	1869
8	4	12	18.44769	1661
9	1	2	18.00232	1621
10	1	2	16.8924	1521

Response= answer to the question

Delay state= in milliseconds x 10
Duration= in seconds, until prompt is dismissed
Frames= total frames with that particular state of delay

Briefly looking at the test results; we can see that answers from the user were reflective and representative of the state of delay, even though introduction and change in delay state was randomized. At zero millisecond delay (run count 2 & 4), answer was 1 (stable) and at 120 millisecond delay (run count 7 & 8) answer was 4 (unstable).

Questionnaires

2 questionnaires were filled by the participants; one taken before test and one after the test. Information collected through these questionnaires is anonymous.

The questionnaires were designed to gather relevant data and to provide insights surrounding the user study.

The first questionnaire (taken before the test) had following enlisted questions and some preselected answers/options (in order):

1. Gender

   Male, Female, Transgender, Non-binary/Non-conforming, Prefer not to respond
2. Age
3. Experience level [with video games in general]

   (1) No experience, (2), (3) some experience, (4), (5) extensive experience
4. Experience level [with VR]

   (1) No experience, (2), (3) some experience, (4), (5) extensive experience
5. Frequency of play [in general]

   Never, sometimes, sometimes; once every week, sometimes; more than once a week, regular
6. Do you feel motion sickness in car or on a swing etc. (?)

   Never, sometimes, every time

The second questionnaire was designed to learn about their experience and how they feel after completing the test. This questionnaire also provided them the opportunity to record some detailed observations (optional) and most provided some very informative/useful thoughts

Following enlisted questions and some preselected answers/options (in order) were part of 2nd questionnaire:

1. Did you feel motion sickness?

   Yes, No

2. How was the game?

   (1) Very bad, (2) bad, (3) Fair, (4) Good, (5) very good

3. Please describe your experience (optional)

Demographics

A total 32 participants were involved in the user study. Questionnaires provided important information on demographics of participating users.

All participants were in their 20's and there was good diversity overall on metric's like gender, experience level both with VR and gaming in general.

Of 32 participants, 21 were male (65.6%) and 11 female (34.4%).

Experience with gaming:

Experience level [with video games] *

Svar	Antall	Prosent
1 - No experience	2	6,2 %
2	4	12,5 %
3 - Some experience	11	34,4 %
4	10	31,2 %
5 - Extensive experience	5	15,6 %

More than 80% of the participants had medium to high level of experience with gaming and everyone had played them.

Experience with VR:

Experience level [with VR] *

Svar	Antall	Prosent
1 - No experience	20	62,5 %
2	8	25 %
3 - Some experience	2	6,2 %
4	2	6,2 %
5 - Extensive experience	0	0 %

Over half of the participants had no prior experience with VR. This made training/briefing prior to study being conducted critical. For the first timers, an opportunity was provided to try out the VR with other games prior to the main user study. This helped settling them in with VR environment. They were thoroughly briefed about the controls, positioning of headset, how to navigate the menus and what can they expect when they put on the headset.

Trying VR for the first time can be an overwhelming experience for some and it is important that any user has proper understanding of the surroundings when putting on the headset and entering the VR environment. The systems we used had camera tracking as well and a virtual wall is projected inside the VR environment to make you aware of the end of the active area. This can be quite helpful but when you are really immersed into the VR world you can easily go outside and find the physical limitations.

Figure 4 A participant from pre-test

Frequency of play:

Frequency of play [In general] *

Svar	Antall	Prosent
Never	2	**6,2 %**
Sometimes	15	**46,9 %**
Sometimes; once every week	5	**15,6 %**
Sometimes; more than once a week	3	**9,4 %**
Regular	7	**21,9 %**

A good number of participants had played games in recent times.

Motion sickness:

Do you feel motion sickness in car or on a swing etc *

Svar	Antall	Prosent
Never	15	46,9 %
Sometimes	14	43,8 %
Every time	3	9,4 %

Lastly, nearly half had experienced motion sickness while going on a car ride or swing etc. The test is based on game in which delay is emulated; this can cause motion sickness. This statistic forms basis of a hypothesis discussed in detail later.

Figure 5 Group of participants

4. Results

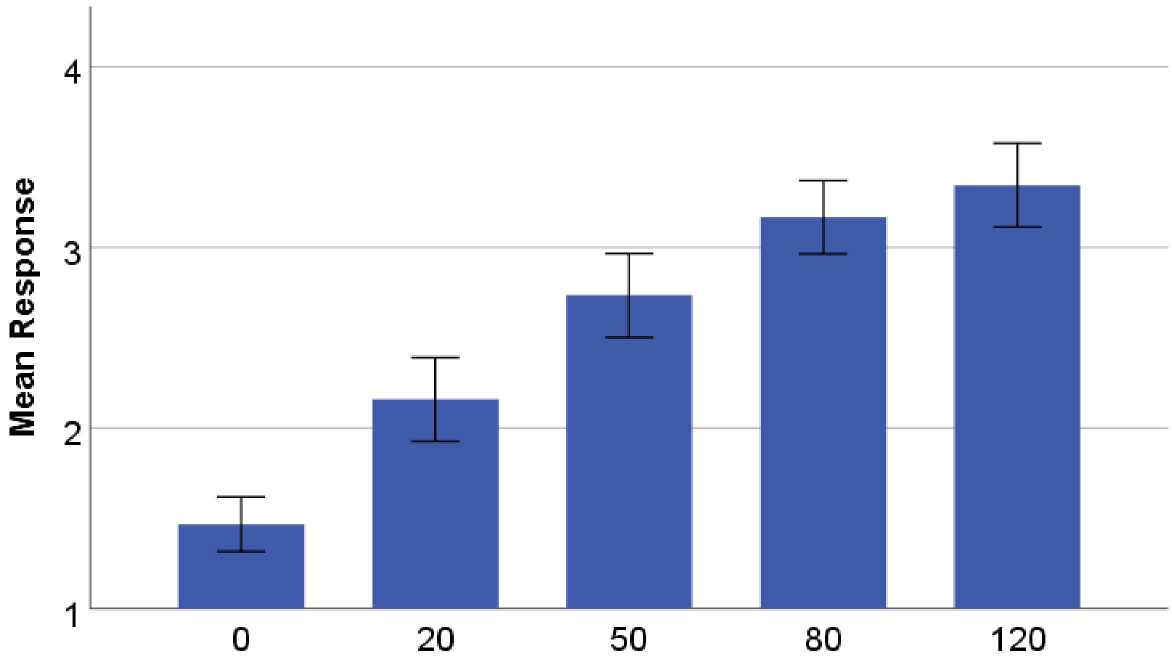

Figure 6 Mean response time

The figure “mean response” portrays score on how stable the participants in the study felt the game was at different states of delay. There is a steep rise in reports on instability in gameplay as early as 20ms of delay state but at the higher end the curve nearly flattens as all participants report unstable gameplay. Between 80ms and 120ms, most rated the experience as 4 (unstable) leaving little difference.

The data, that was collected from the test session, we used different methods to analyse it. First we ran Friedman test and found that statistically, there is substantial difference across delay levels , X2 (4) = 126.85, p =< .001. This test was followed by a post hoc Wilcoxon test and with Bonferroni corrections, which revealed that even a 20 ms added delay (Mean = 2.20, SD =.91) effects how the participants experience delay, having a difference ($p < .001$) from the 0 ms delay (M=1.48, SD=.59). The participants The participants gave significantly lower score for 50 ms (M = 2.77, SD =.89), 80 ms (M = 3.13, SD =.78), and 120 ms (M = 3.41, SD =.83) added delay. It was noted that, the differences between 80 ms and 120 ms delay ($p < 0.4$), were not much significant.

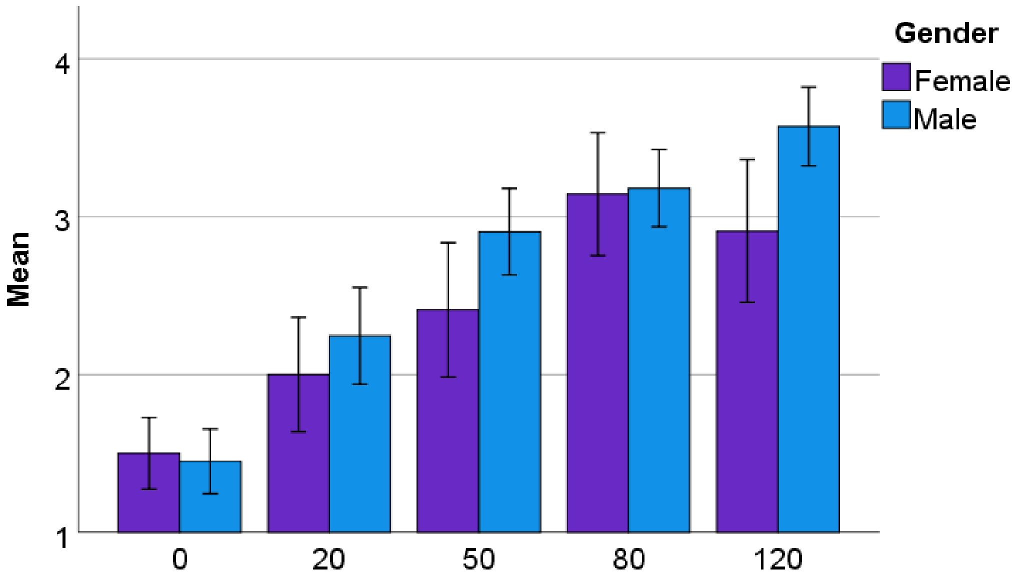

Figure 7 Gender based distribution

Next, we looked into factors such as gender and past experience of the participants with virtual reality. To analyse the difference across genders, we used Mann – Whitney U test, this revealed that there is no difference at 0ms, 20ms and 80ms on score of perceived delay in between genders. Right beyond the centre point of the scale at 50 ms [U= 329.00, p= .04] and until 120 ms [U= 284.00, p= .004] there was a big difference. The figure "mean response" from different "genders" shows this trend i.e. male participants reporting more frequently and being more sensitive to delay at higher end.

We also looked into the experience factor as well. The experience level of users was recorded through a survey prior to the test sessions. The following figure shows the ratings participants at different experience levels gave for the perceived delay.

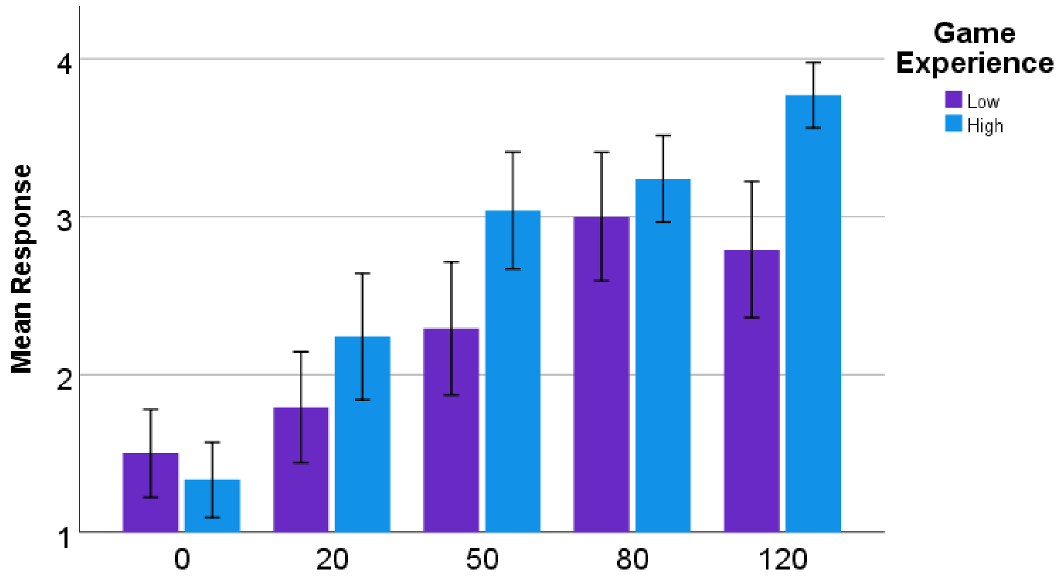

Figure 8 Experience based distribution

We ran Mann – Whitney U test again and learned that there is a big difference between participants with different levels of experience past midpoint 50 ms [U= 335, p =.01] and 120ms delay [U= 263, p < .001], this result had similarities with gender-based evaluation. There was again little difference at 0ms, 20 and 80ms in between different experience levels of participants. Participants with higher level of experience were more sensitive to delay.

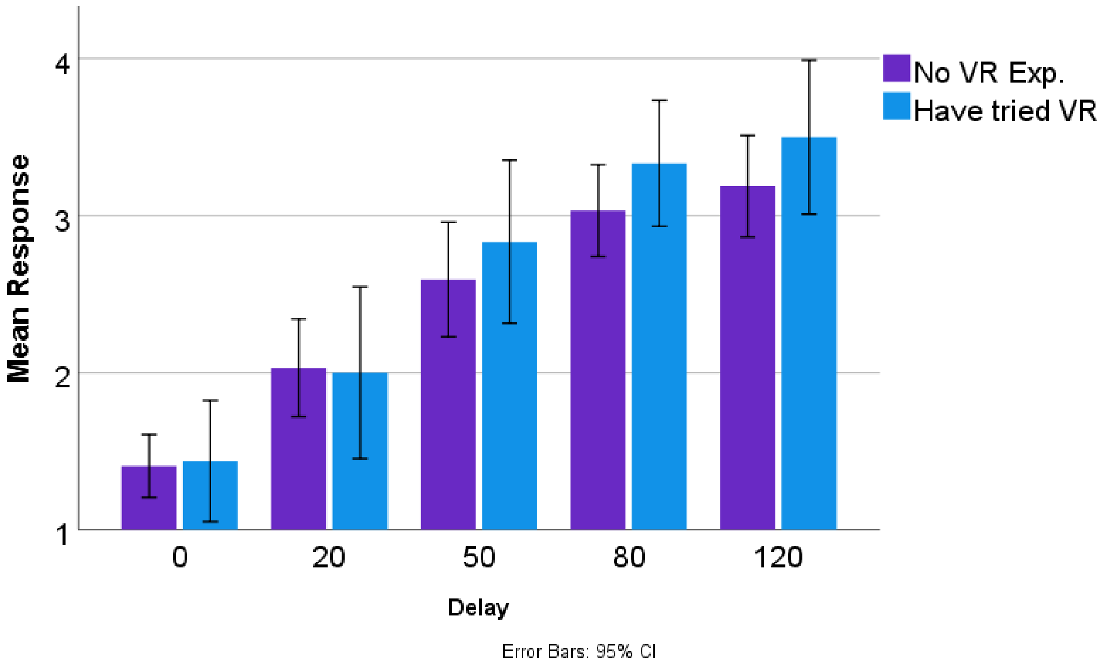

Figure 9 VR experience

At the end of the study, users were asked to answer a questionnaire about if they felt motion sickness or not. Figure 10 shows the results from that survey.

Did you feel motion sickness? *

Answer	Number of	Percentage
Yes	23	**71.9%**
No	9	**28.1%**

Figure 10 Survey results about motion sickness

Nearly 71% reported that they experienced motion sickness and recorded further comments such as feeling discomfort, dizziness, sickness etc. Participants also tried to avoid motion sickness by closing eyes or limiting their movement.

Discussion

This thesis looks into the effects stability has on gaming experience, particularly in virtual reality and we try to find if human factors such as gender and experience level of participants has effect on this as well. When a game is run on a system; any system, be it 2-dimensional output on a display or virtual reality, there is inherent delay at different levels and components of a system. It could be network delay, delay in the output to a display, input delay through connected peripherals, constraints from compute power, limited memory etc. Any or high level of delay on top of this would significantly deteriorate use experience, this is consistent to prior studies. The user study showed that delay as low as 20ms was noticeable and it became more and more apparent as the value of it increased. At the higher end of the scale, every participant noticed and reported delay. Additionally, this led to majority (about three quarters) of participants reporting that they are experiencing motion sickness.

If we compare the results of delay in virtual reality with typical delay in a system on which a game is run from cloud in a 2d environment; tolerance level of delay is much lower for a user. Due to the very nature of how input is registered in a virtual reality environment, even a smaller value of delay is noticed, and we found out that, that number could be as low as 20ms.

We also compared the results for perceived delay under the factors which directly relate to the participants. These were gender and experience level. We found that, male participants are more prone to experience delay and at higher level in contrast to female participants. This divide is narrower and eventually disappeared once we moved down on the scale. At the lower end, all experienced and reported delay. The participants in the study had different levels of experience. We observed that, the ones with high level of experience were also more sensitive to any delay introduced during the gameplay but similar to difference in feedback from different genders, perceived delay level reduced and equalled with higher values and everyone reported delay at the top end of the scale (120ms).

In the future, finding tolerance at the lower end of the scale and introducing smaller value states of delay would be something of interest. Finding a definite or most common tolerance level would be incredibly helpful in setting a standard for quality of experience at the development stage of games in virtual reality.

Conclusion

Delay in VR can be noticeable very soon and this study shows that even a lag of 20ms becomes noticeable. It of course worsens once you move up on number of delay in milliseconds. Generally, the participants were able to correctly rate their experience as expected once the delay state changed with a higher value.

Delay in VR hugely effects the experience, as shown in prior studies. Delay in VR has different consequences to delay in regular 2d gameplay output on a screen. Since most modern VR systems use motion sensors or camera tracking to determine the position of head and controllers also have motion sensors; any delayed output on the screen after an action is performed can start to make user feel motion sickness. Some users might have high tolerance to motion sickness but eventually they can also feel the effects and at the very least have a bad experience.

There was a really good ratio of female to male participants in the user testing and this lead to another interesting finding that; male participants were able to catch signs of delayed output consistently at higher end of the scale. Except for few exceptions, all male participants were able to notice delay sooner but as the delay intensity got higher pass the mid point of 50ms, they were experiencing delay more often compared to female participants.

A question related to prior experience was also floated and when experience level was matched with their rating on a state of delay, we noticed a trend. The participants with higher experience level were more likely to report delay at a later stage with higher value of delay. Additionally, even though introduction of a certain delay state was randomized, they still were immediately able to catch it with a predictable ratings. Participants with experience in VR or gaming in general had a better understanding of any non optimal gameplay conditions. This is why they were immediately able to recognize a drop or increase in/normalization of response time. Also noticeable among experienced participants was that they had higher level of tolerance to getting motion sickness and they were able to finish the session without any severely unpleasant or extreme case of motion sickness.

Irrespective of experience levels and gender, any out of ordinary delay in output was noticeable across the participants at certain levels. Higher value delay state were rated worse/unplayable with consensus. Even though there were some differences at lower value delay states on how quickly they are reported due to different experience level of participants and different genders but any future work in this area should consider adding and having a closer look at lower values on the test scale. The differences in experience level and genders has effect on delay sensitivity in VR and it matches research in research on audivisual asynchrony.

It is clear that any or higher level of delay in VR gaming can deteriorate the experience of gameplay and is really off putting. Game developers must avoid or minimize the factors responsible for this. Not only this is bad for quality of experience but also can have direct effects such as motion sickness which can move people away from trying VR again.

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Appendices

Test results

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
1	MMFra	0	4	2	38.66742	3481	Yes
		0	4	12	23.8772	2150	
		0	4	8	17.69238	1593	
		0	1	0	17.54633	1580	
		0	1	0	17.28906	1556	
		0	2	2	27.76532	2501	
		0	3	5	18.37177	1654	
		0	3	5	19.22388	1731	
		0	4	12	17.33636	1561	
		0	4	8	18.67999	1682	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
2	ANSpa	0	3	5	24.43353	2200	No
		0	4	12	17.99171	1620	
		0	3	8	18.00154	1621	
		0	1	2	17.87955	1610	
		0	1	5	19.19153	1728	
		0	1	0	17.79208	1602	
		0	3	8	17.75818	1599	
		0	1	0	16.97061	1528	
		0	3	12	17.23114	1551	
		0	2	2	16.39899	1477	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
3	ARAFra	0	4	5	28.98721	2610	Yes
		0	4	12	22.37949	2015	
		0	4	2	20.31879	1502	
		0	2	2	17.88474	1611	
		0	3	12	18.9924	1710	
		0	1	0	18.50049	1666	
		0	3	8	19.31427	1739	
		0	3	5	17.69189	1593	
		0	1	0	17.78552	1602	
		0	2	8	74.61545	6717	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
4	JABGer	0		2			Yes
		0		0			
		0		8			

		0	4	12	21.15655	1905	
		0	3	2	21.33138	1921	
		0	4	12	32.23082	2902	
		0	2	0	19.61311	1766	
		0	4	5	19.80293	1783	
		0	4	8	23.95457	2157	
		0	3	5	24.46698	2199	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
5	LANor	0	1	0	21.08208	1875	Yes
		0	3	5	17.524	1578	
		0	4	12	17.22477	1551	
		0	2	8	17.75742	1599	
		0	2	5	16.81544	1514	
		0	3	8	16.90338	1522	
		0	1	2	17.5365	1579	
		0	1	2	16.32536	1470	
		0	3	12	16.49072	1485	
		0	1	0	16.43782	1480	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
6	STNo	0	3	12	29.43447	2649	Yes
		0	3	8	22.80041	2053	
		0	2	0	18.22092	1641	
		0	3	5	19.04043	1714	
		0	4	8	17.31379	1559	
		0	3	5	18.47908	1664	
		0	4	12	20.85527	1878	
		0	2	0	21.07965	1898	
		0	3	2	18.91289	1703	
		0	3	2	17.62309	1587	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
7	SANo	0	3	0	38.20758	3440	Yes
		0	4	2	26.11006	2351	
		0	4	8	22.66675	2041	
		0	4	12	20.25671	1824	
		0	4	8	25.64655	2309	
		0	4	5	17.19986	1549	
		0	4	12	18.67041	1681	
		0	4	0	28.5303	2569	
		0	2	2	21.35901	1923	
		0	3	5	16.82227	1515	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
8	HUFra	0	1	12	32.37889	2916	No
		0	1	5	32.84014	2957	
		0	1	0	19.43501	1750	
		0	1	5	18.55713	1671	
		0	1	0	21.00204	1891	
		0	1	8	16.55927	1491	
		0	1	2	22.49561	2026	
		0	1	12	25.74402	2318	
		0	1	2	24.29247	2187	
		0	1	8	18.56937	1672	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
9	ADRom	0	2	2	37.15466	3346	Yes
		0	4	12	18.54395	1670	
		0	1	0	19.09451	1719	
		0	3	2	31.17307	2807	
		0	4	12	19.45758	1752	
		0	3	5	25.03247	2254	
		0	1	0	19.22543	1731	
		0	4	8	18.25836	1644	
		0	4	5	18.78	1691	
		0	4	8	17.14526	1544	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
10	SANor	0	3	5	41.54179	3741	Yes
		0	1	2	17.36853	1564	
		0	1	0	16.65831	1500	
		0	4	5	23.68956	2131	
		0	1	0	17.23601	1552	
		0	2	2	19.22498	1731	
		0	4	8	16.65836	1500	
		0	4	8	16.62715	1497	
		0	4	12	16.24619	1463	
		0	4	12	17.15802	1545	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
11	GDNor	0	4	2	23.39296	2107	Yes
		0	1	0	21.17827	1907	
		0	4	5	18.64836	1679	
		0	4	12	19.46631	1753	
		0	3	8	18.87036	1699	
		0	3	2	17.39929	1567	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
		0	3	5	17.30112	1558	
		0	4	8	17.09717	1539	
		0	1	0	17.21317	1550	
		0	4	12	17.64841	1589	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
12	MADLeb	0	3	5	30.75669	2770	Yes
		0	3	12	22.11319	1991	
		0	2	8	20.41048	1838	
		0	2	2	18.5692	1672	
		0	2	8	17.79855	1603	
		0	3	2	19.00713	1711	
		0	2	0	20.17952	1817	
		0	3	5	19.10118	1720	
		0	4	12	18.91449	1703	
		0	2	0	22.29636	2008	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
13	ESGre	0	3	8	29.72362	2674	No
		0	2	8	19.04541	1714	
		0	3	2	27.57541	2483	
		0	2	12	19.6917	1773	
		0	2	5	21.75618	1958	
		0	2	0	21.03462	1894	
		0	3	5	17.70291	1594	
		0	3	12	19.21231	1730	
		0	2	2	18.30304	1648	
		0	2	0	20.6026	1855	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
14	JPPol	0	2	8	34.38946	3097	No
		0	3	0	19.62341	1767	
		0	3	8	18.99051	1710	
		0	3	12	19.19087	1728	
		0	3	5	23.7108	2135	
		0	2	0	19.002	1711	
		0	2	5	17.32707	1560	
		0	2	2	17.51355	1577	
		0	3	12	17.70291	1594	
		0	3	2	18.36807	1654	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
15	MWPol	0	3	12	26.52579	2389	Yes

			0	3	8	21.33623	1921	
			0	2	2	17.62284	1587	
			0	2	5	17.38249	1565	
			0	2	2	17.12537	1542	
			0	2	12	19.2876	1737	
			0	2	0	17.16154	1545	
			0	3	8	19.61237	1766	
			0	2	5	16.98196	1529	
			0	2	0	22.177	1997	

#	ID	Round Count		Response	Delay state	Duration	Frames	Did you feel motion sickness?
16	LUCSpa		0	4	8	20.0336	1804	Yes
			0	1	0	21.48987	1935	
			0	4	5	16.84589	1517	
			0	3	5	18.49142	1665	
			0	4	12	17.35812	1563	
			0	2	0	19.14648	1724	
			0	3	2	17.33569	1561	
			0	4	12	17.28632	1557	
			0	3	8	17.35303	1562	
			0	2	2	18.03668	1623	

#	ID	Round Count		Response	Delay state	Duration	Frames	Did you feel motion sickness?
17	AMCGre		0	3	2	31.58951	2845	Yes
			0	4	12	19.04626	1715	
			0	2	0	23.25488	2089	
			0	3	2	19.46884	1752	
			0	4	5	17.02481	1533	
			0	1	0	16.73883	1507	
			0	3	8	17.68463	1593	
			0	3	12	17.28046	1556	
			0	3	8	16.39648	1476	
			0	2	5	17.8595	1608	

#	ID	Round Count		Response	Delay state	Duration	Frames	Did you feel motion sickness?
18	JAGer		0	3	2	26.95905	2428	Yes
			0	1	0	20.46721	1843	
			0	4	12	16.81598	1514	
			0	4	5	19.13254	1723	
			0	2	2	18.29236	1647	
			0	3	8	17.34766	1562	
			0	4	12	16.61345	1496	
			0	2	0	19.91269	1793	
			0	3	5	17.4245	1569	

		0	3	8	17.82602	1605	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
19	LBGer	0	1	2	51.73724	4659	Yes
		0	2	12	31.13997	2804	
		0	4	12	28.23761	2543	
		0	1	0	21.78296	1961	
		0	2	0	24.65659	2220	
		0	4	8	20.44449	1841	
		0	1	2	21.74448	1958	
		0	4	8	22.23401	2002	
		0	3	5	20.30194	1828	
		0	2	5	19.7796	1780	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
20	MREng	0	4	12	21.84987	1968	Yes
		0	3	8	18.92319	1704	
		0	1	0	18.03694	1624	
		0	3	5	19.14581	1724	
		0	4	12	25.29907	2278	
		0	2	2	17.61395	1586	
		0	1	5	16.91449	1523	
		0	2	8	17.26862	1555	
		0	1	0	17.68259	1592	
		0	1	2	16.73563	1507	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
21	FGIta	0	4	12	27.70407	2494	Yes
		0	4	5	22.79976	2053	
		0	4	8	20.87941	1880	
		0	3	0	21.93443	1975	
		0	3	5	19.63589	1768	
		0	3	8	20.62308	1857	
		0	2	2	19.33578	1741	
		0	4	12	17.36983	1564	
		0	3	2	18.76932	1690	
		0	2	0	17.09174	1539	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
22	MBBel	0	3	12	54.33455	4893	Yes
		0	1	2	29.09747	2620	
		0	1	0	22.74463	2048	
		0	1	5	30.36295	2734	

		0	3	5	23.97821	2159	
		0	2	8	23.84467	2147	
		0	2	2	26.48715	2385	
		0	2	12	19.9671	1798	
		0	1	0	35.2309	3172	
		0	2	8	19.24554	1733	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
23	INWGer	0	1	0	46.19446	4160	No
		0	1	0	24.1431	2174	
		0	1	2	33.884	3051	
		0	1	5	32.1185	2892	
		0	3	12	43.64969	2955	
		0	1	2	40.39246	3637	
		0	3	8	30.66278	2761	
		0	3	8	23.35352	2103	
		0	2	12	23.237	2092	
		0	1	5	17.94574	1616	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
24	VSDNor	0	4	5	22.80481	2054	Yes
		0	3	5	22.8665	2059	
		0	1	0	18.10161	1630	
		0	2	0	18.34772	1652	
		0	4	12	18.57761	1673	
		0	2	2	17.98401	1619	
		0	4	8	18.65604	1680	
		0	3	8	16.69266	1503	
		0	4	12	17.51001	1577	
		0	1	2	18.76285	1689	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
25	DLNor	0	2	8	29.88984	2692	No
		0	1	0	20.02504	1803	
		0	4	12	18.97966	1709	
		0	3	8	17.02466	1533	
		0	1	0	17.43668	1570	
		0	2	5	18.25835	1644	
		0	3	5	18.00183	1621	
		0	4	12	17.12715	1542	
		0	1	2	16.50337	1486	
		0	1	2	17.30251	1558	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
26	MMGre	0	1	0	48.9053	4396	Yes
		0	2	5	22.79987	2053	
		0	2	2	21.06718	1897	
		0	1	2	21.78995	1962	
		0	1	5	21.3783	1923	
		0	1	12	19.2912	1737	
		0	1	8	20.96771	1888	
		0	2	12	23.52328	2118	
		0	1	0	20.91214	1883	
		0	1	8	17.71448	1595	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
27	SUTTNor	0	2	12	37.24246	3352	No
		0	1	0	21.61169	1946	
		0	1	5	18.36383	1654	
		0	3	12	19.02795	1713	
		0	1	2	28.85461	2597	
		0	3	5	18.30139	1646	
		0	4	8	16.98117	1529	
		0	1	0	19.53314	1759	
		0	2	2	18.92712	1704	
		0	4	8	18.59146	1674	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
28	JSSpa	0	3	8	23.85361	2145	Yes
		0	2	2	22.02435	1981	
		0	4	5	18.35744	1653	
		0	4	12	17.19154	1548	
		0	3	2	18.27957	1646	
		0	2	8	20.06709	1807	
		0	3	5	18.4808	1664	
		0	2	0	35.35207	3183	
		0	4	12	17.79694	1603	
		0	2	0	19.0519	1715	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
29	SVNor	0	4	12	62.84406	5659	Yes
		0	1	0	23.2338	2092	
		0	4	2	36.7359	3308	
		0	4	8	16.58167	1493	
		0	1	0	17.31485	1559	
		0	4	12	16.80212	1513	

		0	4	8	16.41589	1478	
		0	3	2	18.27988	1646	
		0	3	5	17.2587	1554	
		0	3	5	17.32379	1560	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
30	AGBSpa	0	4	8	24.20191	2180	No
		0	3	8	25.15802	2265	
		0	3	5	18.95779	1707	
		0	3	2	22.42171	2019	
		0	2	0	18.14809	1634	
		0	1	0	19.90218	1792	
		0	2	2	28.24203	2543	
		0	2	12	22.27856	2006	
		0	3	12	21.70036	1954	
		0	2	5	28.32002	2550	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
31	FDBel	0	4	8	26.54929	2390	Yes
		0	4	12	18.52295	1668	
		0	3	2	23.10043	2080	
		0	2	2	20.11209	1811	
		0	3	5	18.76816	1690	
		0	2	0	19.21381	1730	
		0	4	12	17.62625	1586	
		0	3	5	21.93417	1972	
		0	2	0	25.06534	2255	
		0	3	8	21.22308	1910	

#	ID	Round Count	Response	Delay state	Duration	Frames	Did you feel motion sickness?
32	APSpa	0	2	2	23.12857	2083	No
		0	4	12	23.41071	2108	
		0	2	5	18.83543	1696	
		0	2	2	17.51276	1577	
		0	2	0	17.75986	1599	
		0	1	12	18.53548	1669	
		0	3	5	17.10184	1540	
		0	2	0	16.94876	1526	
		0	4	8	17.65971	1590	
		0	3	8	16.80051	1513	

Additional methods of data analysis

Oneway

ANOVA

Response

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	147.382	4	36.846	51.795	.000
Within Groups	219.103	308	.711		
Total	366.486	312			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Response

Tukey HSD

(I) Delay state	(J) Delay state	Mean Difference (I-J)	Std. Error	Sig.	95% ... Lower Bound
0	2	-.691*	.151	.000	-1.11
	5	-1.267*	.150	.000	-1.68
	8	-1.699*	.153	.000	-2.12
	12	-1.876*	.150	.000	-2.29
2	0	.691*	.151	.000	.28
	5	-.576*	.150	.001	-.99
	8	-1.008*	.152	.000	-1.43
	12	-1.185*	.150	.000	-1.60
5	0	1.267*	.150	.000	.85
	2	.576*	.150	.001	.16
	8	-.432*	.152	.037	-.85
	12	-.609*	.149	.001	-1.02
8	0	1.699*	.153	.000	1.28
	2	1.008*	.152	.000	.59
	5	.432*	.152	.037	.02

	12	-.177	.152	.769	-.59
12	0	1.876*	.150	.000	1.46
	2	1.185*	.150	.000	.77

Multiple Comparisons

Dependent Variable: Response

Tukey HSD

(I) Delay state	(J) Delay state	95% Confidence . Upper Bound
0	2	-.28
	5	-.85
	8	-1.28
	12	-1.46
2	0	1.11
	5	-.16
	8	-.59
	12	-.77
5	0	1.68
	2	.99
	8	-.02
	12	-.20
8	0	2.12
	2	1.43
	5	.85
	12	.24
12	0	2.29
	2	1.60

Multiple Comparisons

Dependent Variable: Response

Tukey HSD

(I) Delay state	(J) Delay state	Mean Difference (I-J)	Std. Error	Sig.	95% ... Lower Bound

(I) Delay state	(J) Delay state	95% Confidence Upper Bound
	5	1.02
	8	.59

	5	.609*	.149	.001	.20
	8	.177	.152	.769	-.24

Multiple Comparisons

Dependent Variable: Response

Tukey HSD

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

Response

a,b[a,b]

Tukey HSD

Delay state	N	Subset for alpha = 0.05 1	2	3	4
0	62	1.47			
2	63		2.16		
5	64			2.73	
8	60				3.17
12	64				3.34
Sig.		1.000	1.000	1.000	.766

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 62.564.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Published work