On the Peripheral Application of HMD Devices in Infantry Simulation

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ABSTRACT

The purpose of this paper is to present the results of an attempt carried out at the IDF Ground Forces Command Battle-Lab to integrate a Head Mounted Display (HMD) device as part of a peripheral-equipment simulator for infantry. The Battle-Lab is a research oriented simulation environment, where combat scenarios with many multiple human participants can be run to examine the effects novel concepts or technologies could have on scenario outcomes.

Previously (Michael et. Al, 2014) an attempt was made at the Lab to evaluate an HMD’s effectiveness as an exclusive display for infantry simulation. At that time, while the device tested was found to have had a positive impact on a participant’s motivation and spatial awareness, it was found lacking in the field of visual fidelity, as well as responsible for an increased incidence of simulation sickness among its wearers.

As a result of the previous evaluation it was decided to proceed with the integration of the device, but only in supplementary peripheral simulators. These included a pair of binoculars made available to an infantry soldier for use concurrently with a standard flat-screen first-person infantry simulation.

However, given the device’s reputation for causing simulation sickness, and our previous experience with the phenomena, it was decided to monitor the participants’ experience closely. This task was accomplished through simple after-action self-review supplemented by a more detailed daily debriefing with the Simulation Sickness Questionnaire.

In this paper are presented the results of this monitoring throughout a series of scenarios carried out at the Battle-Lab in 2014, conclusions from the gathered data, as well as lessons learned from the process of both building and studying simulation sickness in the use of peripheral simulators with HMD integration.

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BACKGROUND

The Lab

In effect, Israel's Ground Forces Command Battle Laboratory (the "Battle-Lab" or "Lab" for short) is a single simulator. Its purpose is to simulate Ground-Forces combat scenarios, into which novel combat systems can be deployed and their role in scenario progression evaluated. As the lab simulates a virtual environment, this process can be made possible before such systems can be tested "out in the field", or even before they are entirely thought out. As a result, the lab can operate at a stage when rapid iteration on a concept (or even its dismissal) is still possible. Thus, research can be conducted before a considerable amount of money has been spent to bring it into the physical world.

However, reliable tools do not yet exist to simulate human behavior in these new and novel situations, the recording of which is the very purpose behind the lab's existence.

To solve this problem, the lab relies on an array of game-like combat stations for human participation. Supporting as many as 100 concurrent and cooperating participants at a time, they are not too dissimilar from a modern first-person perspective video game, controlled by a keyboard and mouse, and viewed from a typical LCD monitor. Unlike video-games, they are tuned towards tactical realism, rather than enjoyable play.

The keyboard-mouse-screen combination is a necessary abstraction for the lab's purposes, with the mouse and keyboard representing movement in the simulated environment with hands and feet. While this exclusion may be considered by a lab report, it is not directly modeled at the lab.

Head Mounted Displays

With these abstractions come inherit flaws, and occasionally new technologies can help "fill in the gap", by creating more directly "playful"[1] paradigms for control. A steering wheel and pedal system for example, does away with the need for mouse and keyboard by providing a tangible wheel and pedals for participants to control the simulated vehicle directly with.

For us at the lab, "Head Mounted Displays" (HMDs) are another playful alternative to mouse and keyboard. An HMD is a display mounted on a user's head, which covers the entirety of the user's field of view with a stereoscopic display of the scenario. Current generation models also track the position and orientation of a user's head so that the displayed image can be made to match it in three-dimensional space.

Ideally such technology could be used as an interface for the entire infantry combat experience, but that level of fidelity isn't always a necessary for the lab's purposes.

There also exists a strong association between the technology of head mounted displays and the phenomena of Simulation Sickness (Häkkinen, J., Vuori, T., & Puhakka; Patterson, & Muth. 2010; Merhi, Faugloire, Flanagan & Stoffregen, 2007), which can leave users incapacitated to some degree, negating many advantages gained by abandoning the abstracted approach. It is because of these phenomena that (for the time being) the lab has adopted a more careful and considered approach to deploying HMD systems in infantry simulation.

[1] In this context "playful controls" is used to refer to more natural interfaces, which are played with directly, and do not represent an abstracted intermediary step between user and simulation (as do the traditional mouse and keyboard controls). Sometimes these are referred to as Ludic Interfaces, though often the latter has a more general meaning.

One such approach is through the peripheral application of HMD devices. By using an HMD to simulate a peripheral system being operated by the user: binoculars, out-the-hatch views, etc. the user is given control of when to wear the device and when not to. Users are no longer trapped wearing a system that makes them feel ill, and can more freely adjust usage to suit their personal preference.

Simulation Sickness

It is generally asserted that Simulation Sickness is either a form of, or somehow related to motion sickness, and sufferers of both report many of the same symptoms such as nausea, disorientation, eye strain, and even vomiting (LaViola, 2000).

Any and all of these symptoms are unwanted at the lab for empathic, hygienic, and research reasons, as they could potentially contaminate the subject’s behavior in the simulated scenario.

The standard method applied for measuring Simulation Sickness at the lab is through the Simulation Sickness Questionnaire (SSQ), as created by and presented in their 1993 paper by Kennedy, Lane, Berbaum, and Lilienthal (Kennedy, Lane, Berbaum, and Lilienthal, 1993). The 16 point SSQ was created by applying a factor analysis to the results of many hundreds of samples of an earlier “Motion Sickness Questionnaire”, and building on those symptoms which were relevant for the study of Simulation Sickness. The SSQ results are used to produce 3 weighted sub-scores: Nausea, Oculomotor Discomfort, and Disorientation, which are then used to calculate a Total Severity Score incorporating all three. As presented in their paper, it is a post-exposure test for healthy subjects.

Although not proven, it is believed that the root cause of Motion Sickness is either a sensory conflict, caused by a discrepancy between what is reported by the vestibular system and what the brain processes from its optic center (LaViola, 2000), or as a result of the body struggling to adapt its posture in environments where it doesn’t have the appropriate (or has conflicting) information to do so (LaViola, 2000; Stoffregen & Riccio, 1991).

Postural instability has been shown to precede symptoms of (when they are measured with the SSQ) both Motion Sickness in controlled environments (Smart, Stoffregen & Bardy, 2002), and even to some degree Simulation Sickness when using HMDs (Häkkinen, Vuori & Puhakka, 2002). However, whether it is in some way involved in the cause of symptoms, or is simply an earlier symptom, is as of yet undetermined.

The lab has relatively little prior experience with Simulation Sickness. Its low to negligible incidence in earlier lab infantry simulators, coupled with its tendency to disappear after continued exposure to the simulation for lab subjects, meant that the introduction of Head Mounted Displays was the first time the issue had to be directly engaged with by lab personnel.

Given that our experiences with earlier simulators tended to support the idea that long term exposure could lead to adaptation overcoming Simulation Sickness, we have generally adopted it as our main approach in trying to resolve the issue.

Previous Integration Attempts

Michael, Rockah & Minkov (2014) presented a previous attempt to integrate last generation HMD technology with IDF GFC Battle-Lab infrastructure. Although the attempt described in that paper was successful, it showed a non-negligible incidence of simulation sickness among experiment subjects. These results raised questions about the viability of using the devices in full length combat simulations, and the experience formed the basis for the design of the current study.

PRESENT STUDY

In the winter of 2014 an experiment was conducted at the lab, which featured – in addition to several other combat stations – 4 HMD Equipped infantry stations where the HMD represented binoculars available to the participant in parallel to a standard lab dismounted simulation.

The Head Mounted Displays used in this experiment were second generation Rift devices from Oculus VR (the DK2), and the simulator integrated with them was built using Presagis' Vega Prime (version 5), using a custom lab integration.

Participants were instructed only to use the binoculars when the infantry simulation they were attached to was stationary, and to keep their use of either one exclusive. The binocular simulation supported 360-degree movement of the head, as well as limited motion along the x-y-z axes.

The experiment's purpose was not to test the effectiveness of Head Mounted Displays as tools for improving peripheral simulations, or to make any observations about Head Mounted Displays in general. As such there was no purposeful manipulation of variables such as frame-rate, resolution or refresh-rate in an attempt to see which would cause the most Sickness, as that would have tampered with the results and purpose of the greater experiment at play.

Instead, all participants using HMDs were monitored for symptoms of simulation sickness and how their experiences developed over time. It is this monitoring forms the basis for this paper.

Purpose

Throughout the years, adaptation over time to the simulation environment has been the main tool used by the lab when dealing with the effects of simulation sickness, and the research shows that it is often the most effective tool short of pharmaceuticals for combating Simulation and Motion Sicknesses (Johnson, 2005). Participants in lab experiments are not fixed, no single participant from one experiment can be expected to participate in the next, and any adaptation that is expected to occur in one can occur only within the timeframe of the experiment itself. It then becomes imperative to try and ascertain whether adaptation is an applicable cure for simulation sickness within the time-table of a lab experiment.

Methods

Data on simulation sickness from the experiment was collected through 2 major channels. The first, was through a simple single question questionnaire asking users to rate Nausea on a scale of 0 to 3, presented immediately at the end of every scenario. The second, was through a daily Simulation Sickness Questionnaire, filed out following the last scenario of each day by all participants who had used an HMD equipped station on that day.

Young, Adelstein & Ellis, (2007) showed a connection between the use of a pre-exposure SSQ and a bias towards higher results on a post-exposure questionnaire. While there was no pre-exposure survey among participants in the study discussed in this paper, as it is presented as unnecessary by the original SSQ paper (Kennedy, Lane, Berbaum, and Lilienthal, 1993), by the end of the first day when the SSQ was first submitted to participates, all would have already responded several times to the one answer questionnaire. By day two, all would have filled out the SSQ of the previous day. In effect all participants were aware that they were being studied for symptoms of Nausea to some degree before virtually all scenarios, and to the other symptoms tested by the SSQ for all but the first day. It is therefore important to remember that the responses given by participants may have an upward bias when compared to the results of other studies when only a single post-exposure test was given.

As the scenarios were held within our simulation framework, we could also (through metadata collected by our systems) correlate responses from the shorter one answer questionnaire with other scenario data, such as time of day, length, etc.

Participants

The group followed was small (6, of which only 4 were monitored for a significant period of time), and as such the data presented here cannot promise an accurate demographically diverse slice of the population.

The treatment of each subject of the experiment should then be considered its own case-study, and this paper an aggregate of these user stories. As a result of the small sample size we are unable to make assertions about the general population, but we can use the higher level of detail obtained by the prolonged study to enlighten ourselves as to the experiences of particular users in larger groups we have worked with outside the confines of an organized research initiative.

Within this paper the often complementary and redundant results between users have aggregated and displayed graphically while their eccentricities have been textually detailed and expanded upon.

All participants were between the ages of 18-21, male, and all were active duty combat soldiers in the IDF at the time.

Legend

In the following sections a series of charts will be presented, each representing either the responses given by participants to a specific field of the Simulation Sickness Questionnaire, or representing an overall sub-score or sub-total score of the SSQ.

Within these charts the X axis represents the encounter day the response was given at, with Encounter Day meaning the number of days the Subject had been using the HMD up to that point. This is with the exception however of graphs representing the shorter After Action Questionnaire, whose X axis will either represent date and time, and time of day, and will be denoted on the chart itself.

The Y axis in all represents the severity of the symptom reported, with 0 representing no incidence whatsoever, and 3 representing severe incidence of the symptom. This is with the exception of graphs representing sub-scores, whose max possible value will be denoted in their headings. As several subjects responded simultaneously with the same responses on the same encounter day, a recurring representation on the chart will be marked as darker relative to the amount of responses it represents, with more responses meaning a darker spot. The Daily average is represented by a smaller red dot, and is also represented by a red liner trend line.

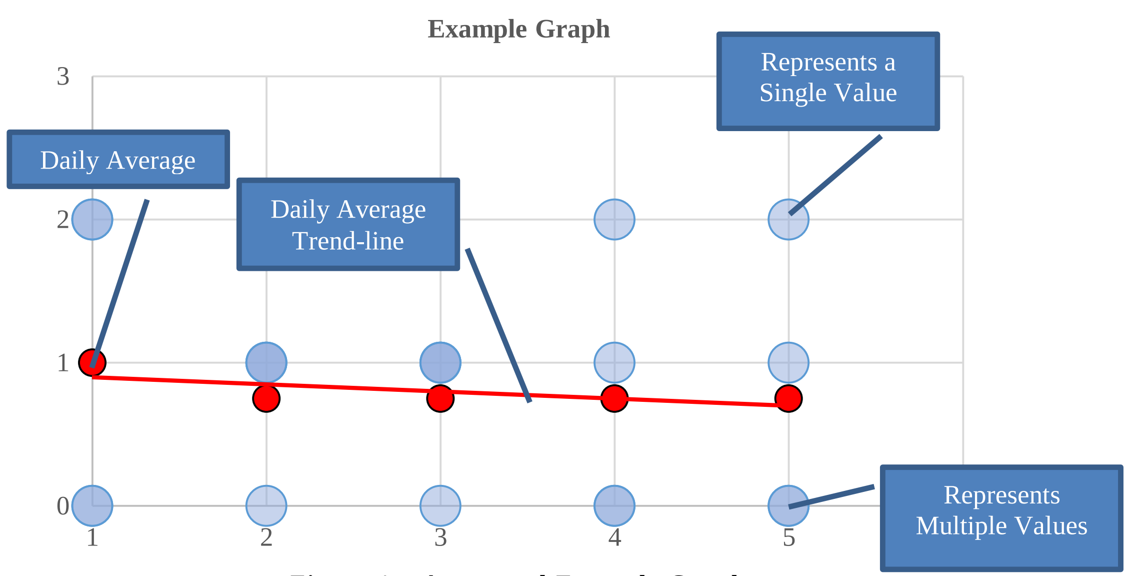

Figure 1 – Annotated Example Graph

Maximum Y axis values for Subs-scores are 159.18 for Oculomotor, 200.34 for Nausea, and 292.32 for disorientation. The maximum total severity score is 235.62.

The responses represented in these graphs are from subjects A, D, E, & F, as these are the only participants which had between 5 and 6 encounter days with the device, henceforth they shall be referred to as the Main Data Group. Subjects B & C had only one and two encounter days with the device respectively, and their responses to the SSQ will be taken into account separately.

Daily Questionnaires

Subjects B & C
Due to the shifting of personal during the earlier stage of the experiments, Subjects B & C spent between one and two days with a head mounted display device. Uniquely however, they both had some of the most aggressive responses to a head mounted display recorded; setting the experiment record for three overall highest SSQ scores at 100.98 and 86.02 for C, and 67.32 for B out of a total of 235.62 respectively. For comparisons sake, the highest overall score recorded from the main data group on their first encounter day was 48.62, and 41.14 when picking highest from among all days.

Fatigue may have something to do with B's score, given that he reported feeling severely fatigued on his encounter day.

C (the so-called record holder) on the other hand, reported only mild fatigue in both his cases, and may represent an acute reaction to using the device. It's important to note that his second day did show some signs of improvement, reporting no Nausea at all, only "a little" stomach awareness, clearer vision, and less dizziness. This may be offset however by a rise in fullness of the head, the appearance of Stomach Awareness (perhaps representing mild nausea), and severe Eye Strain.

C's data also indicates a significantly higher than average sub-score for Oculomotor symptoms, above average disorientation, and a much higher than average nausea.

B's uniqueness seems to steam from a significantly higher than average Oculomotor score, as the rest of his subtotals are either in line with those of other subjects, or even slightly below average.

It is unfortunate given these unique responses that further data could not be collected from these subjects.

Main Data Group
Symptoms with Negligible Incidence

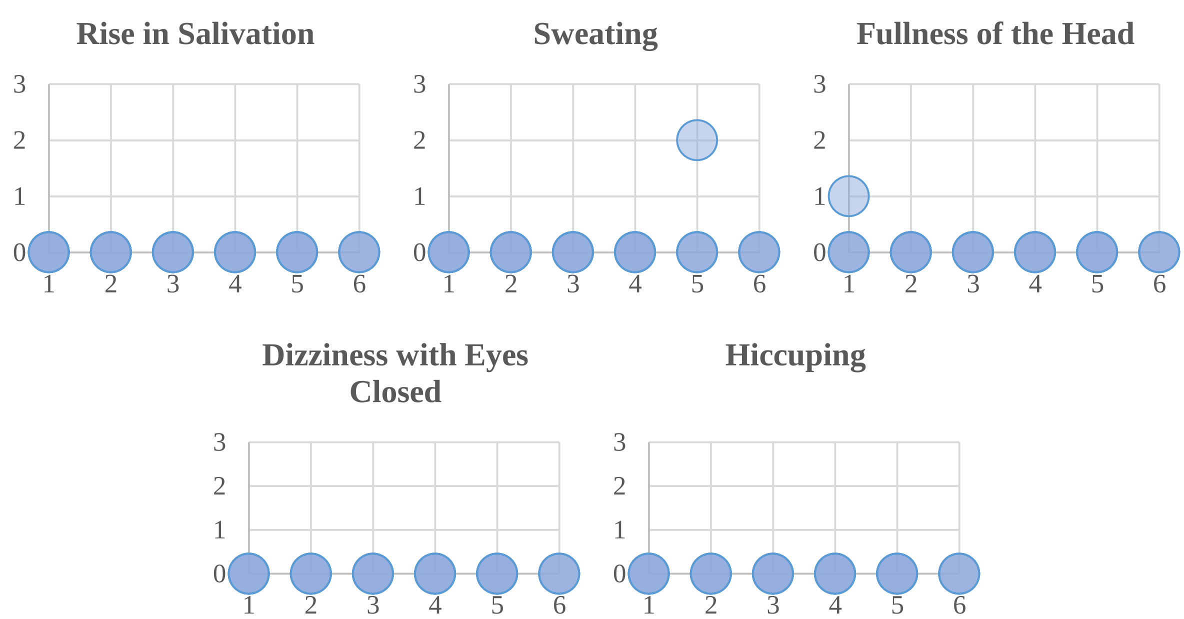

Figure 2 – Graphs representing Increase in Salivation, Sweating, Fullness of the Head, Dizziness with Eyes Closed, and Hiccups[2]

[2] A mistranslation meant that the field of Burping in the original SSQ was misinterpreted as Hiccups in the Hebrew version given to subjects at the lab. After this error was noted, and when prompted at the end of the experiment, no

Not every symptom represented by the SSQ showed up among our test subjects, and yet others only appeared with a single incidence reported with the lowest non-zero value possible.

Neither Increased Salivation, Sweating, Dizziness with Eyes Closed, nor Hiccups had any prevalence among our subjects in either our main body of subjects graphically represented above, or subjects B &C, with the exception of sweating experienced out of the blue at day 5 by Subject-E.

Fullness of the Head, was encountered by subjects only twice, both times on the first encounter day, by subjects F and C respectively. The double appearance may be indicative that its prevalence is associated with first time use of the device, however, the low value, coupled by its lack of reappearance means it remains too little information from which to make a concrete call.

General Discomfort and Overall SSQ Score

In a way, as interpreted by our test subjects, both the field "General Discomfort", and their overall SSQ scores were both ways of quantitatively measuring answers to the same question: "How are you feeling?"

It is surprising then, that they contain a contradiction.

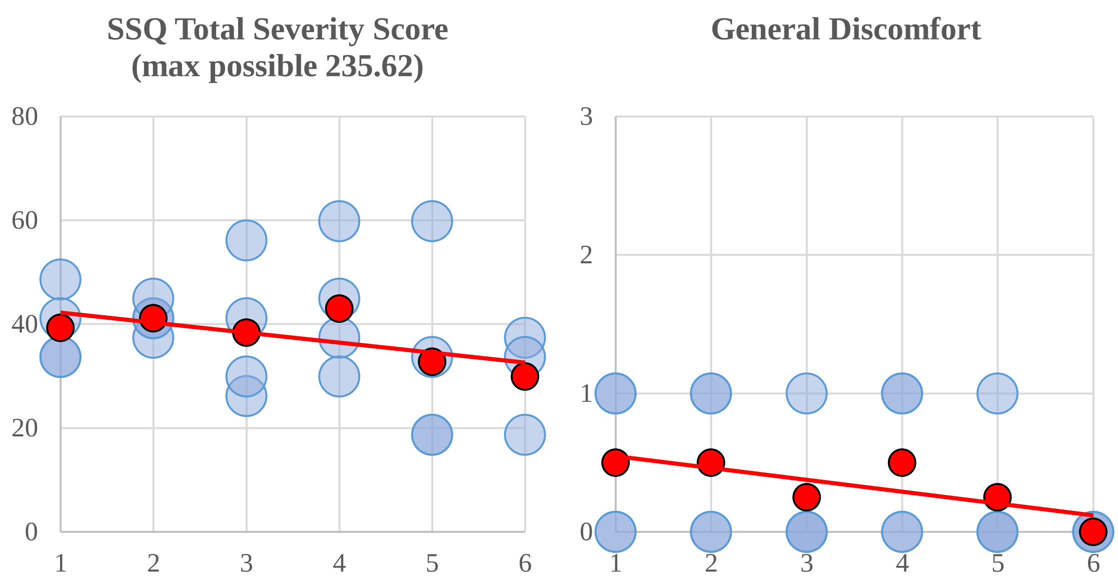

Figure 3 – Graphs for Overall SSQ Score, and General Discomfort

When we read the general discomfort graph, we see that Day 5 has three out of four participants reporting no general discomfort whatsoever, while day 6 has no reports of discomfort at all.

Meanwhile, reading the Overall SSQ score, we see that while there does appear to be a slight downward trend in scores, negative symptoms are in-fact still being reported by users, even though the previous graph clearly shows they reported feeling OK.

There are a couple of ways to interpret this data.

Firstly, one might assume a mixture between misunderstanding, and outside influence. Symptoms such as fatigue can be drastically affected by outside actors, such as lack of sleep, and are yet still calculated in the overall SSQ scores.

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subjects reported burping (outside of the lunchroom) in general, or in association with any given scenario during the time of the experiment.

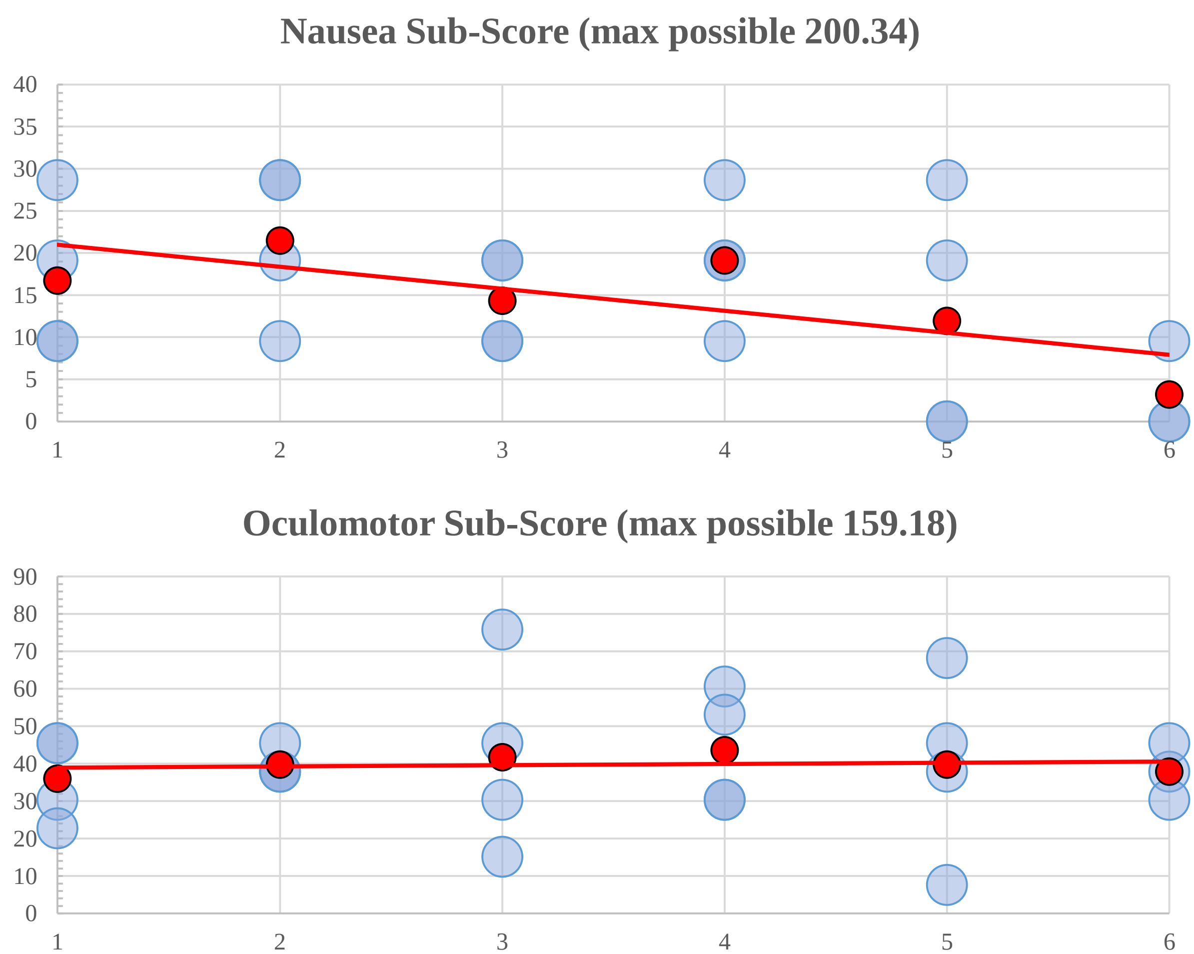
Perhaps users opted to ignore outside factors when considering General Discomfort. It is possible subjects felt such mild symptoms, that while they registered in their particular field, they weren't a contributor to the overall feeling.

However, from discussions held with subjects at the end of the experiment, a different possible explanation emerges. The total SSQ result takes into account specific negative symptoms, but subjects can be affected by factors outside those tallied by the test, and sometimes these effects can be positive. Subjects reported feeling excited to be using an HMD, in the lab's experiment the previous summer we showed subjects reported feeling more immersed and driven in an experiment then they or their compatriots had been when not using the device. It is possible that this excitement can help subjects get past negative symptoms, and may warrant further investigation.

SSQ Sub-scores: Nausea, Disorientation, and Oculomotor Symptoms

Initially, Nausea was singled out as the lab's greatest concern when using HMD devices, so it was encouraging that a downward trend in the nausea sub-score of the SSQ was the most noticeable among them. With a drop from an average score of 16.97 on the first day, to 11.93 on the last day when all subjects in the main data group were involved, and 3.18 on the last day of the experiment overall. When looking at the data individually, a divide is apparent between subjects A & E which hovered around a nausea value, and subjects D & F which witness a steady a gradual drop, both of who's final calculations on day 6 reported no Nausea whatsoever.

As nausea was orally reported to be the most debilitating symptom group among subjects, its low prevalence at the end may go a long way to explaining the low general discomfort scores described in the previous section.



Figures 4 & 5 – Graphs for SSQ Nausea Sub-Score & SSQ Oculomotor Sub-Score

Although the trend-line for the Oculomotor Sub-Score appears relatively stable, it actually represents a balanced combination unique incidence trends among users.

Looking at Subjects A, F, & E for example (Figure 6), we see a relatively stable incidence, trending either consistently in downwards as is the case for subject E, or hovering around the same score as is the case with A & F, suddenly and seemingly randomly peaking. This might seem to indicate that a particular factor is at play here provoking these incidents. This factor has as of the writing of this paper, eluded its authors.

Subject-D remains the only one not to display these peaks in Oculomotor Sub-score, although if they are caused by an as-of-yet unidentified factor, it is not unlikely that they would eventually have occurred.

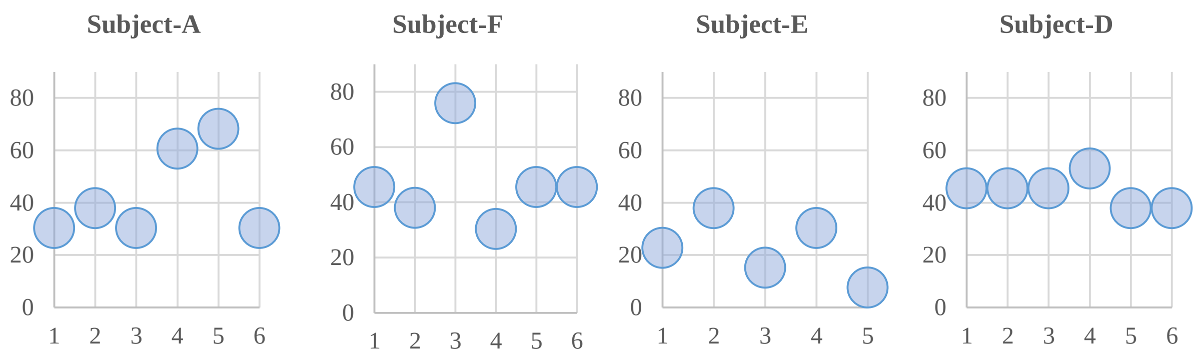


Figure 6 – Graphs for main data groups subjects' SSQ Oculomotor Sub-Score out a max possible score of 159.18

With the exception of Subject-A, the Disorientation Sub-scores for all other subjects in the Main Data Group fell over the course of the experiment, with subjects D & E to falling zero and a very low value respectively on their last encounter days, and Subject-F managing to reduce his from 83.52 on day 1 to 55.69 by day 6.

Subject-A's scores rose slightly until about the fourth encounter day, but returning to what they were on the first two days at the experiments end.

From conversations with the subjects after the experiment was over, it would seem that this reduction in values has something to do with learning to orient one's self when using the device, and with learning to read the virtual environment and imply one's own orientation in it.

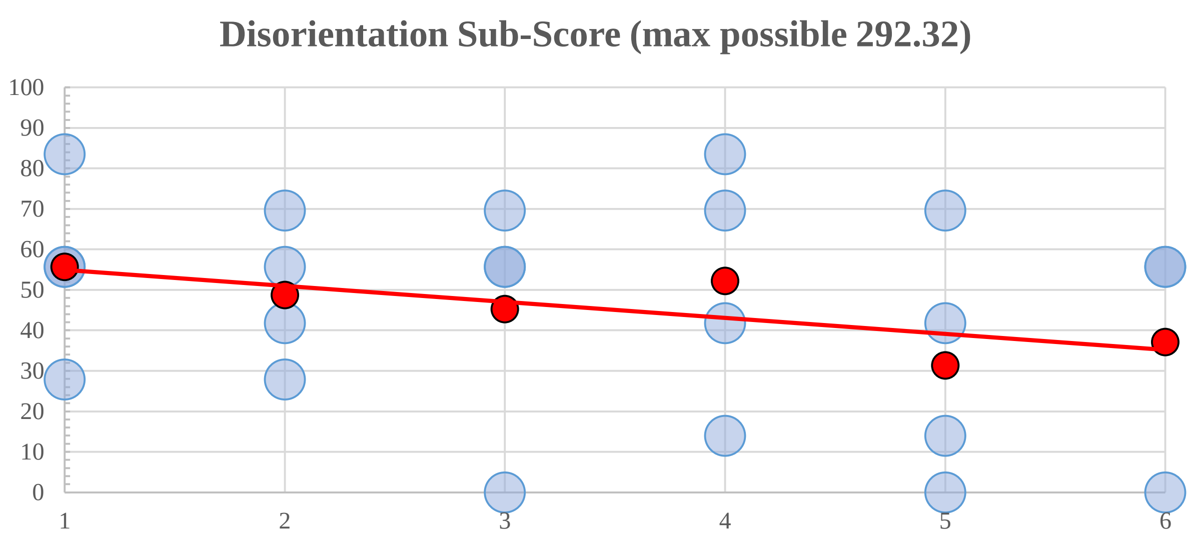


Figure 7 – Graph for SSQ Disorientation Sub-Score

After Action Questionnaires

At the end of each scenario participants were requested to fill out a questionnaire were they were asked a series of questions about the scenario they had just completed. Among these questions was a request to rank one's own experience of nausea at the scenario's conclusion.

Data from these questionnaires could be correlated with information such as time-of-day and scenario length, and was intended to give a finer grained view of that particular symptom.

The question asked matched the SSQ field of the same name, and users were requested to answer with values between 0 and 3, with 0 representing no incidence of nausea at all, and 3 representing severe incidence.

When this questionnaire was designed, an event where participants would be rotated between stations during the experiment was not considered, and as such there is no way to tie the data about a particular station to a particular subject on days when such rotations are known to have occurred.

Additionally, it transpired that only two subjects (D & E) bothered at all to fill out this questionnaire consistently, with Subjects F & A either filling it out only twice, or never at all respectively.

As can be seen from the above graphs (Figure 8), scenario length didn't seem to have a consistent visible effect on reported nausea. At the time of writing no significant correlation has been found between any of the data gathered on these scenarios, and nausea reported at their conclusion.

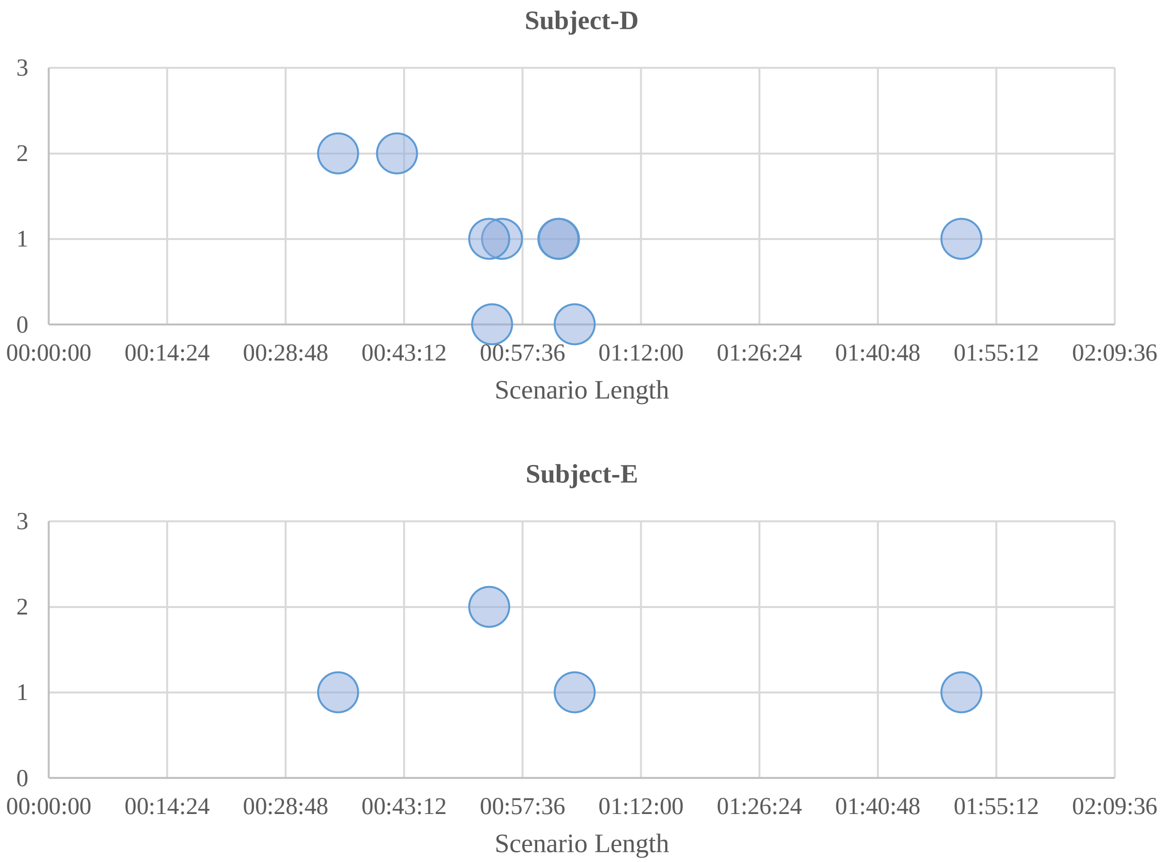


Figure 8 – After action nausea review data from Subjects E & D set against scenario length

AFTERWORD

All in all, we have not produced a "Last word" on the subject of Head Mounted Displays. Given that even going-in we knew we would have a small sample size, it can be inferred that this was never our intention. Admittedly we were hoping that in addition to providing some answers on the effects of adaptation on simulation sickness, some clear evocative trend would emerge pointing us in some particular area of research. Other than seeming to confirm that within our small sample size, adaptation over time did seem to reduce symptoms, no earth-shattering discoveries have been made.

What we have created for ourselves are the beginnings of a database of user experiences. By using the SSQ we have created 4 users stories which we can compare with later experiments in the hopes of creating an even larger database from which more inclusive trends can be evaluated. Hopefully by having adhered to these methods, the data presented in this paper could be used in a limited form for comparison in other, similar research initiatives.

These stories also constitute a touchstone that we can use to try and corroborate user experiences when working outside the confines of a directed research initiative, to try and further our understanding of the particular experiences of our subjects by matching them (when possible) with those of subjects already researched.

On Peripheral Use

To our moderate satisfaction, the concept of utilizing Head Mounted Display devices in peripheral simulations has been shown to be generally effective; a positive rather than negative factor in the user's experience of the simulation.

This however, is in large part to do with the subjective experiences of lab personnel working with the device both in and outside the scope of this particular study in the winter of 2014. We have seen over time that lab personnel have become more adapted to the device as they have worked with it, and qualitative responses gathered from users along the way, as well as data from contemporaries seems to support this conclusion.

From the results of the monitoring itself, we saw a marked drop in Nausea and Disorientation over time from our users, plausibly as a result of adaptation to the device over time. While we cannot say that this will be true for all users, or how common the rates of incidence that were apparent in this study are, they seem to be consistent (albeit in a compounded case) with the general experience of simulation sickness outside the exclusive realm of HMD devices. It remains to be seen whether this trend will continue when more data is collected from more participants.

As previously mentioned, HMDs offer a more playful mode of interaction, as opposed to a more abstracted one. While the loss of abstraction is effective for the lab as it better models realistic behavior from participants in scenarios, this approach may also have some validity in the field of training, where they might represent a closer approximation to the skills being taught by the particular simulation.

However, HMD technology has yet to fully mature, and while it has been found to be effective in the peripheral role, we would suggest only the upmost caution when approaching the field of fully-immersed simulation.

Additionally, at the time of writing, the resolution provided to each eye in the device tested was relatively low, and represents in-itself an anachronism that either must be in mind when choosing what to simulate with it, or be abstracted-around by finding alternative approaches to highlight detail to the user that would otherwise have been available to him in a real-life setting.

"Excitement"

In a previous section we examined the role the excitement participants had for using these devices as a plausible motivational component in their willingness to see past the technology's faults.

Although a visit to the lab is a novel experience for most participants, a long series of experiments can become somewhat monotonous, the use of HMDs is novel enough[3] that its users may feel special and be motivated by their unique experience when compared to their collogues.

Our previous formal examination (Michael, Rockah, & Minkov, 2014) had shown that users do tend to feel more motivated and immersed when using the device. The source of this motivation being a technical aspect of it, rather than simply a reaction to its novelty is currently unknown.

Only time (or a particularly focused study) will tell whether excitement will remain an effective factor if and when the technology proliferates beyond the niche it currently occupies, and its novelty is reduced for the general population.

Future Work

It is our intention to continue to chronicle Simulation Sickness incidence through the use of the SSQ for the foreseeable future in an attempt to broaden the demographic representation of our data.

We are also interested in the collection of more meta-data from each scenario that could potentially be correlated with the SSQ, such as scenario length, and the intensity of HMD use within the scenario itself. This process would also include tying the SSQ to particular scenarios rather than to the ends of particular days for the sake of better correlation.

Additionally, the results of this study have made apparent for us the need for a short pre-exposure questionnaire. Not a rehearsal of the SSQ, but a collection of background information on the user's predisposition at the time of examination. For example, as it would appeared fatigue had played a role in the SSQ results of participants over the course of the study, it could be useful to know which participants had slept the appropriate amount of time the night before, and which had not.

An aborted attempt was made to apply the lessons of this study to a later experiment in the spring of 2015, a description of this attempt is available in Appendix A of this paper.

Our current focus remains confirming the feasibility of the technology in the peripheral realm, and not the discovery of novel implementations to reduce the incidence of Simulation Sickness, We still believe adaptation may be the most effective counter to the phenomena. Once we feel the technology has matured enough to support more than just peripheral simulation, or a novel approach to such an undertaking brought up, we might again consider approaching the subject of a full-immersion HMD backed simulation.

[3] Nearly all our participants reported that they had never used an HMD prior to their arrival at the lab

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