Postural Stability and Sickness Symptoms after HMD Use

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Abstract-- **A head-mounted display use may induce various effects and symptoms. In our experiment we measured the time course of postural sway and sickness symptoms for 60 minutes after a head-mounted display (HMD) use. The results indicate that game playing with stereoscopic graphics and fast movement stimuli produced slightly increased postural sway and sickness symptoms for 20-30 minutes after the HMD use. However, there was no correlation between disorientation symptoms and sway. We also found out that watching a movie with the HMD was so relaxing that it made the participants feel better after the immersion.**

Keywords: **Head-mounted display, aftereffects, postural sway, simulator sickness, nausea, eye strain, disorientation.**

I. Introduction

Using a head-mounted display (HMD) can produce a number of adverse symptoms and effects, which can appear both during and after the HMD use. Some users experience simulator sickness symptoms that can be anything from general discomfort to headache or nausea [1]. Although the symptoms resemble motion sickness, they form a distinct symptom cluster in which symptoms are usually less severe and affect a smaller proportion of exposed population [2,3].

The subjective symptoms are sometimes accompanied by disruption in performance. For example perception, motor performance and postural stability can be disrupted [1]. The subjective symptoms affect the enjoyableness of the use, but degraded performance can also be a safety issue, because the aftereffects can affect the user's ability to walk, drive a car, use machinery or perform other sensomotorically demanding tasks. Furthermore, in worst case such effects can persist for hours after the immersion [4].

A. Symptoms and effects occur during adaptation

The HMD induced symptoms and effects are related to the adaptation that occurs when the spatiotemporal relationships between actions and perceptions change. For example, in an HMD the viewing system can change the relationship between accommodation and convergence or a tracking system can change the relationship between the initiation of a hand movement and the corresponding visual feedback. The plasticity of the human sensory and motor systems allows us to recalibrate the systems for optimal performance fairly quickly, so users can learn to perform in an environment with visual distortions and delays. However, the adaptation period is often accompanied by subjective symptoms and disrupted performance. When an HMD is used, the user experiences two adaptation periods. Firstly, the user must adapt from the normal environment to the virtual environment. Secondly, after the HMD use the adaptive changes must be reversed via a postimmersion readaptation period.

B. Postural instability

Postural instability is caused by incongruities among the spatiotemporal input from sensory and motor systems. The ability to maintain posture is based on predictable relations among visual, vestibular and somatosensory sensations. When these relations change, the resulting sensory conflict creates a need for adaptation and the posture control systems are temporarily disturbed [3].

The results from studies investigating postural instability after head-mounted display or flight simulator use have shown variable results. Some studies have shown that small amounts of postural sway are induced [1]. However, due to different equipment, tasks, immersion times and postural sway measurement methods, there have been large differences in the results [1,3,4,5].

C. The purpose of this study

In this study we used of a force plate for postural stability measurement. Many studies have measured the initial postural sway after the immersion, but we also wanted to measure the time course of the effect, so repeated measurements were performed and sickness questionnaires were administered for an hour after the immersion. Our experiment included a vision screening procedure and a background questionnaire so that background variables could be controlled. We were especially interested in the role of gender, age and previous HMD experience in the symptom severity and sway.

II. Methods

A. Participants

Nokia Research Center personnel were used as participants. The total number of participants was 60. The mean age was 26.8 years, the oldest participant being 41 years and youngest 18 years. 60 % of participants were males and 20 % were females. 27 % of participants had previous experience on head-mounted displays. The participants were divided to three groups, each containing 20 persons.

B. Apparatus and measurements

The three groups performed different tasks during the experiment. One group viewed a movie ("The English patient") on a television, from a viewing distance of 250 centimeters. The second group watched the same movie with the Olympus EyeTrek FMD-700 HMD. A Philips DVD 711 was used to play the movie. The third group played a racing game (Need for Speed Porsche 2000) with the FMD-700 in stereoscopic mode. A Microsoft SideWinder racing wheel and pedals was used to control the game.

The participants watching the movie sat on a comfortable cushioned chair with head and arm rests. The participants playing the game sat on an office chair without arm or head rests.

The physical properties of the FMD-700 were measured with the measuring system described by Levola and Viinikanoja [8] and are described in table 1. (More detailed measurements can be found in the original paper [8]). The FMD-700 was modified to enable stereoscopic viewing and Wicked3D drivers were used to convert the game graphics to stereoscopic stimuli.

Table 1. Olympus FMD 700 physical parameters

HMD and virtual image geometry	Value
Focus distance at center	>2.5 m
Focus distance at edge	1.0 m
Convergence distance	2.6 m
Diagonal FOV	35.5 deg
Horizontal FOV	28.5 deg
Vertical FOV	21.1 deg

An AccuSway^{Plus} 50 cm x 50 cm force plate was used to measure postural stability. The force plate was connected to the serial port of a computer in which the data was collected by SwayWin95 software. The average speed of center-of-pressure (COP) along its path was calculated as a measure of postural stability.

The Simulator Sickness Questionnaire (SSQ) was used to quantify subjective symptoms [2]. The SSQ consists of 16 questions that produce three subscales corresponding to simulator sickness symptom clusters: nausea, oculomotor symptoms and disorientation (Table 2. Two symptoms contribute to more than one subscale, so they are mentioned twice in the table). Also a total score that represents the complete symptom level is derived from the SSQ.

The SSQ contains a 4-point scale for all items. The experiment participants use the scale to rate the severity of experienced symptoms ("none" which is scored as 0, "slight" which is scored as 1, "moderate" which is scored as 2, and "severe" which is scored as 3). The subscale scores are calculated by summing the ratings (0,1,2, or 3) of symptoms in each subscale and multiplying the resulting score by a weight score which has been defined by varimax factor weights during SSQ development [2]. The weight scores for each subscale are: Nausea = 9.54, Oculomotor = 7.58, Disorientation = 13.92 and total score = 3.74.

According to Kennedy et al. [2] the absolute SSQ score acquired after the immersion should be used. However, because individual differences in the rating scales and answering strategies are large, we also compared the pre- and post-immersion ratings.

C. Procedure

The experimental procedure (Figure 1.) was started with collecting the background information and screening the participants' vision. The background questionnaire included questions about previous HMD experience, computer game playing, visual strain symptoms, motion sickness susceptibility and alcohol and other substance use. The vision screening included near and far visual acuity, stereo acuity, near point of accommodation, near point of convergence, near horizontal phoria, AC/C ratio and the refraction state of the lens of each eye.

Before the experiment started, the participants filled the Simulator Sickness Questionnaire (SSQ) and Visual Symptoms Questionnaire (VSQ) and their sway level was measured with eyes open and closed. The speed of the center-of-pressure (COP) was used as a measure for the postural sway. The participants stood in the platform for 30 seconds with eyes open and for 30 seconds with eyes closed. The participants stood with feet side by side with their arms folded and wore their normal shoes.

Immediately after the task the postural sway was measured again and the measurements continued in 10-minute intervals for 60 minutes. After each sway measurement the participant filled the SSQ and VSQ.

Table 2. SSQ factors

Nausea
General discomfort
Increased salivation
Sweating
Nausea
Difficulty concentrating
Stomach awareness
Burping
Oculomotor
General discomfort
Fatigue
Headache
Eyestrain
Difficulty focusing
Disorientation
Difficulty focusing
Nausea
Fullness of the head
Blurred vision
Dizzy (eyes open)
Dizzy (eyes closed)

III. RESULTS

Due to the space limitations, only sway and SSQ related results are reported in this article. The more detailed analysis concerning the background variables and the visual screen results will be published in a subsequent article.

A. Postural sway

The change in the postural sway speed is shown in Figure 2. The top figure represents results from eyes closed condition and the bottom figure represents results from the eyes closed condition. The results show a clear learning effect, because the sway levels receded quickly during the

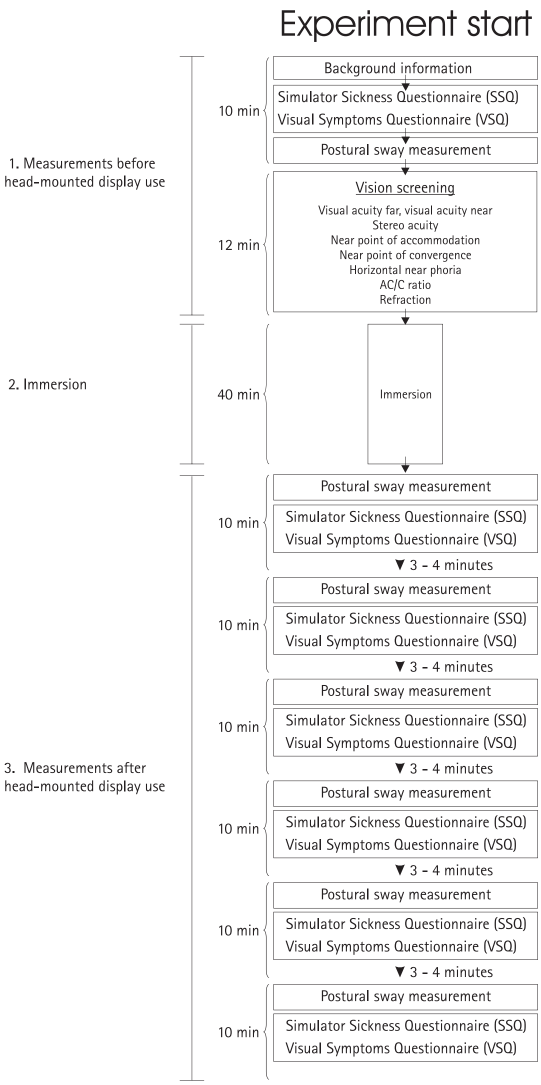

Figure 1. The experimental procedure.

first two trials. The postural sway caused by the game playing was higher than the sway caused by movie watching both when the participants used the HMD (Mann-Whitney, eyes open: $p<0.05$; Eyes closed: $p=0.275$, n.s.) and the TV (Eyes open: $p<0.001$; Eyes closed: $p<0.01$). The difference lasted for 30 minutes after the task (Mann-Whitney, HMD game vs. TV: 1, 10, 20 and 30 min. after the task, eyes open: $p<0.05$).

Surprisingly, the eyes open results indicated higher sway levels (Figure 2. top figure) than the results of the eyes closed condition (Figure 2. bottom figure). This result is completely conflicting earlier results, which strongly suggest that sway should be higher when there is no visual feedback. One possible explanation for the result is the fact that the order of the eyes open and the eyes closed conditions was not randomized. The eyes open condition was always the first in each sway measurement and the eyes closed condition was the second. This probably caused an increase in the eyes open sway and a decrease in the eyes closed condition sway. The former may have occurred because the participant always stepped to the force plate before the measurement, so the postural sway may not have been properly stabilized compared to the eyes closed condition in which the posture was probably much more stabile, because the participant was already standing on the force plate.

B. Sickness symptom, absolute values

Figure 3 represent the absolute SSQ symptom levels immediately after the task. The scores have been calculated according to the specifications of Kennedy et al. [4], i.e., the post-immersion scores have not been subtracted from the pre-immersion scores.

The stereoscopic game playing caused highest total symptom level (Figure 3. HMD game vs. Television: Mann-Whitney, $z=-2.047$, $p<0.05$). Watching a 2D movie with the same HMD caused lower total symptom level, which suggests that the stereoscopic movement stimuli might have caused additional symptoms. However, the difference was not statistically significant (HMD game vs. HMD movie, Mann-Whitney, $z=-0.332, p<0.740$).

The SSQ subscale scores (Figure 3.) indicated that the nausea and disorientation symptoms were higher with the game playing, which suggests that the fast movement and stereoscopic stimuli may have caused some additional symptoms. However, the differences were not statistically significant (HMD game vs. HMD movie, SSQ/N: Mann-Whitney, $z=-1.625, p=0.104$; SSQ/D: Mann-Whitney, $z=-0.940$, $p=0.669$). The lack of statistical significance could also be caused by the differences in the initial symptom level of each subject. Because of this possibility, we calculated also the relative values in which the pre-task symptom level was taken into account.

C. *Sickness symptom, relative values*

The television situation was included in the experiment as a control condition. Interestingly, the post-task symptom levels were elevated also in this case. We hypothesized that the increase might reflect the symptoms the participants were experiencing when they arrived to the experiment. The participation occurred during their normal working day, so certain amount of stress and eye strain may have been present. Because the baseline symptom levels were elevated, we decided to use relative symptom levels in the other parts of the SSQ score analysis. When the relative symptom levels are used, the pre-task symptom score is subtracted from the post-task symptom level so that the change induced by the task is emphasized. All the following SSQ scores in the results section are relative scores.

The change in the total symptom level (Figure 4.) caused by the stereoscopic game playing was significantly worse than the change induced by HMD movie or television condition (HMD game vs. HMD movie, Mann-Whitney, $z=-3.36$, $p=0.001$; HMD game vs. Television, Mann-Whitney, $z=-2.401$, $p<0.05$). The total symptom levels in the HMD movie condition and he television condition were not significantly different.

The stereoscopic game playing caused more nausea symptoms than watching the movie on the television (Mann-Whitney, $=2.79$, $p<0.001$) or watching the movie with the HMD (Mann-Whitney, $z=-5.27$, $p<0.001$). Surprisingly, watching the movie with the HMD caused significantly less symptoms in the nausea factor than watching the film on the television (Mann-Whitney, $z=-3.625$, $p<0.001$).

The difference in nausea symptoms between the HMD game playing and the television watching was significant immediately (1 min) after the task (Mann-Whitney, $z=-2.117$, $p<0.05$). The differences between the HMD game playing and the HMD movie watching were significant 1, 10 and 20 minutes after the task (Mann-Whitney, 1 min: $z=-2.704, p<0.01$; 10 min: $z=-2.123$, $p<0.05$; 20 min: $z=-2.320$, $p<0.05$) and almost significant 30,40,50 and 60 minutes after the task (Mann-Whitney, 30 min: $z=-1.772, p=0.08$; 40 min: $z=-1.689$, $p<0.09$; 50 min: $z=-1.756$, $p=0.08$; 60 min: $z=-1.756$, $p=0.08$). The prolonged difference probably reflects the increased nausea induction in the game condition, but the reduction of the nausea symptoms in the HMD movie situation is also an important factor. These effects are clearly visible in the figure 4., in which the game induced nausea

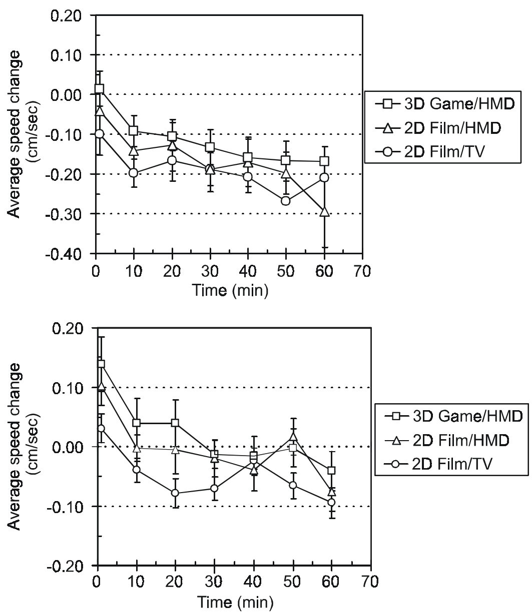

Figure 2. The change in the postural sway in eyes closed (top figure) and eyes open (bottom figure) conditions. Each data represents the difference of pre- and post-task COP speed and is an average from 20 participants. The error bars represent the standard error.

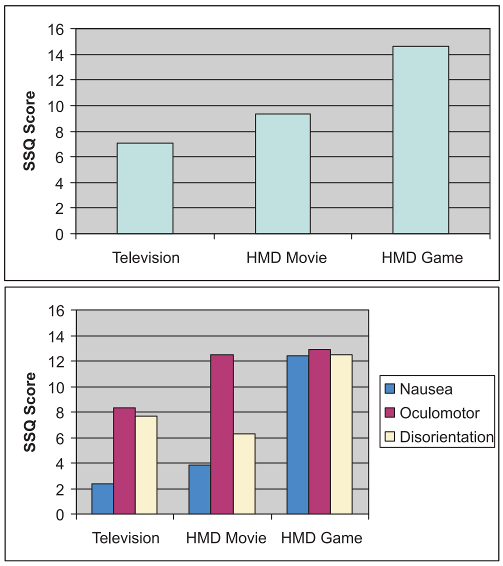

Figure 3. The SSQ scores. The top figure shows the total SSQ scores from each experiment. The scores are absolute values, i.e., pre- and postimmersion values have not been compared. The bottom figure shows the SSQ factor scores from the experiments. The scores are absolute values.

symptoms reach pre-immersion levels 30-40 minutes after the task completion, but the HMD movie induced reduction in nausea symptoms is still visible 60 minutes after the task completion.

The total oculomotor symptom levels were significantly different between the HMD movie condition and the HMD gaming condition (Mann-Whitney, $z=-2.584$, $p=0.01$) and between television condition and gaming (Mann-Whitney, $z=-2.191$, $p<0.05$). The results show that the oculomotor symptoms were most severe immediately after the task completion. There was almost significant effect between the HMD movie condition and the television condition one minute after the task completion (Mann-Whitney, $z=-1.80$, $p=0.07$). The difference between the television watching and the stereoscopic gaming was significantly different immediately after the task completion (Mann-Whitney, $z=-2.847$, $p<0.01$) and almost significant 10 minutes after the task completion (Mann-Whitney, $z=-1.727$, $p=0.08$).

The total differences between disorientation symptoms were significant between the HMD game playing condition and the HMD movie condition (Mann-Whitney, $z=-2.250$, $p<0.05$) and between the HMD game playing and television condition (Mann-Whitney, $z=-2.620$, $p<0.01$).

The symptom levels in the gaming experiment had some relation to gender, with females reporting slightly higher nausea symptoms (Mann-Whitney, $z=-2.028$, $p<0.05$). Also, the older participants (above median age of 25.5) reported higher oculomotor symptom levels than the younger participants (Mann-Whitney, $z=-2.055$, $p<0.05$). The participants with earlier HMD experience did not differ significantly from the other participants.

D. Correlation of the symptoms and the postural sway

There was not correlation between postural sway and subjective disorientation symptoms. This differs from earlier flight simulator results [3] but could be related to the lack of vestibular stimulation in our experiment. Significant correlation was detected only when participants watched film with the HMD. The postural sway (eyes open) at 1 minutes after the task correlated with nausea score (Spearman's rho=0.631, $p<0.01$). This result is difficult to interpret because the HMD movie task induced so little nausea symptoms.

IV. Conclusions

A. Postural sway

The experimental results indicate that there was a small postural sway effect immediately after the stereoscopic game playing with the head-mounted display. However, the increase in the sway speed was small, at a maximum about 0.1 cm/second. For a comparison, if a person consumes a mildly intoxicating dose of ethanol (0.5 ml/kg), the alcohol produces temporary sway increase of 0.4 cm/sec [9]. Still, even a small increase in the postural sway can be significant in some situations, so the users should be instructed not to perform any sensomotorically demanding tasks at least for 10-30 minutes after using a HMD in a task which includes fast movement and stereoscopic stimuli.

The experiment included several factors, which may have affected the results. Firstly, the participants sat in a chair during the experimental task and stood up when the postural sway measurements began. Standing up may have caused additional postural sway, which may have caused noise in the sway data. A test in which participants stand during the HMD exposure might lead to more accurate sway results [10].

Secondly, the order of eyes open and eyes closed conditions was not randomized. The lack of randomization is probably reflected in the results (Figure 2.) in which the change in the postural sway speed is larger in the eyes open condition than in eyes closed condition.

B. Simulator sickness symptoms

Although the original intention of the SSQ developers was to use the absolute SSQ scores, and just exclude the participants with the extreme pre-task scores, our results show that using the difference of pre- and post-task scores has its merits. The absolute SSQ values provide better comparability to a large body of earlier results, but relative values give clearer view of the actual effects, including the possible negative scores.

In our experiment the subjective symptoms were strongest after the stereoscopic game playing, which induced strong nausea and disorientation symptoms. The results indicate that the worst nausea symptoms were experienced within 10 minutes after the task completion.

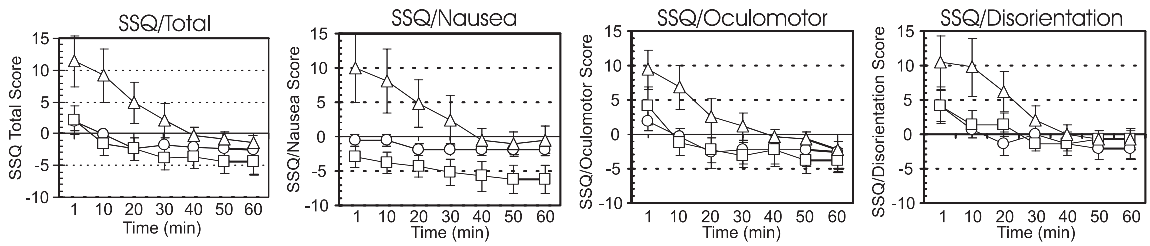

Figure 4. The relative SSQ symptom scores after the task. The leftmost figure shows the SSQ/Total score, the second from the left the SSQ/Nausea scale, the third from the left the SSQ/Oculomotor score and the rightmost SSQ/Disorientation score. Each data point represents the difference between pre- and post-task SSQ scores and is an average from 20 participants. The error bars represent the standard error.

Surprisingly, the relative SSQ scores indicated that watching the movie with the HMD caused negative nausea scores after the task. The result means that participants felt better after the task than before the task. Furthermore, the scores were significantly different from the television condition in which participants watched the same movie. Because SSQ nausea scale includes symptoms that correlate also to stress (general discomfort, difficulty concentrating, stomach awareness, burping), the result might mean that an immersive movie watching experience is more relaxing than conventional movie watching and thus the HMD movie helped the participants to relax during a stressful working day.

Oculomotor symptoms caused by the HMD were partially independent of the stimuli used, because both movie watching and game playing caused significant immediate symptoms. However, the symptoms induced by game playing lasted longer, thus indicating additional visual strain caused by movement and stereoscopic stimuli.

C. Gender and simulator sickness

Females reported higher nausea levels in the gaming experiment. This is in accordance with earlier results, which indicate that females might have slightly higher susceptibility to motion sickness. On the other hand, the result may be related to the so called "macho effect" in which males belittle their symptoms and do not report them.

D. Age and eye strain

Age had some significance in relation to the eye strain symptoms, with older participants reporting more severe symptoms. This might be related to age related changes in the oculomotor system, which makes older participants more susceptible to eye strain. The result suggests that age related changes in vision should be taken into account in the design of future the HMDs.

E. Conclusions

Our experiment shows that future HMD induced postural sway studies should include a detailed visual screening procedure and background questionnaire, because the subjective symptoms and the performance disruptions are closely related to individual differences in visual functioning and gender. There are also other important variables that should be included as background variables, like technology experience, game playing experience, motion sickness susceptibility, and headache susceptibility.

The role of immersion content should also be considered when the head-mounted displays are studied. Our results as well as earlier results indicate that there are no general head-mounted display symptomology, but that the symptoms should always be related to specific tasks and technologies. For example in our experiment the stereoscopic game playing was relatively nauseogenic and induced postural sway, but the movie watching with the same technology was a relaxing experience.

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