Effects of Field of View on Presence, Enjoyment, Memory, and Simulator Sickness in a Virtual Environment

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Abstract

Effects of field-of-view (FOV) in a virtual environment (VE) on presence, enjoyment, memory, and simulator sickness (SS) were studied. A refined scale designed to assess subjects' engagement, enjoyment, and immersion (E^2I) was developed. Items to examine subjects' memory of the VE were included. SS was examined using the Simulator Sickness Questionnaire (SSQ). Using a within-subjects design, data were collected from 10 subjects at four FOVs (60º, 100º, 140º, and 180º). The VE, Crayolaland, was presented in a driving simulator. Results indicated that presence, enjoyment, and SS varied as a function of display FOV. Subjects exhibited higher SSQ and presence subscale scores with increasing FOV. SSQ and presence values approached asymptotes for FOVs beyond 140°. Presence and SS were positively correlated; enjoyment and SS were negatively correlated.

1. Introduction

The primary purposes of this study were to develop a refined scale (E^2I – see below) for evaluation of a user's experience in a VE and to undertake preliminary evaluation of that scale by examining effects as a function of varying FOV. Secondary purposes were to determine relationships between the E^2I scale and the presence and enjoyment subscales as well as between E^2I scores and SS.

1.1 FOV/Presence/Postural Stability

The effectiveness of VEs has been linked to the sense of presence reported by subjects while in those environments. It is generally agreed a wide FOV display can maximize "immersion" in the VE; whereas, narrow FOVs may degrade the sense of presence [13, 16]. In addition, wider FOV displays may contribute to SS. Previous research leads to the following questions: will subjects' sense of presence and SS be a simple linear function of FOV, or will these responses plateau? A previous study indicated that with increasing FOV, subjects exhibited more postural disturbance, which has been suggested as a surrogate measure for SS [4,5]. Dispersion on center of balance continuously increased with increasing FOV from 30º to 180º; i.e., a plateau was not found.

Effects associated with levels of display FOV have been discussed in terms of responses to stimulation of different retinal regions. Simulation of the peripheral retina may be more effective in eliciting self-motion perception (vection) [2, 3, 8], although some studies report vection with FOVs as small as 10º - 25º [19]. The perception of vection may be related to both presence and SS. However, other characteristics of VEs also contribute to SS and presence under different FOV conditions.

1.2 FOV/Memory structure/Enjoyment

Spatial awareness and transfer of knowledge acquired in a VE to a real one have been examined in numerous studies. Differences in FOV have been related to navigation and memory differences [1, 11, 20]. It is likely subjects would exhibit better memory for a VE if they have had the sense of being "in" that environment rather than simply viewing pictures of it. This suggests relationships between memory structure of a VE, presence and spatial knowledge under various FOV conditions. With a larger FOV, subjects may develop more spatial awareness as well as higher sense of presence, and consequently they may exhibit better memory structure of that VE [18]. The memory test itself could focus subjects' attention on the VE and therefore enhance the sense of presence.

Nichols, Haldane, and Wilson studied relationships among presence, enjoyment, and SS during exposure to a VE [12]. They hypothesized that subjects who enjoyed participating in the VE would report higher presence and lower SS. Their results suggested that presence adds to the enjoyment of the VE; a significant correlation between SS and enjoyment was not found. However, a subsequent study described in an unpublished doctoral dissertation did find a negative correlation between SS and enjoyment – see [12].

1.3 E^2I Scale Development

The E^2I scale was developed to assess "engagement, enjoyment, and immersion" experienced by subjects in a VE. Following Witmer and Singer's [21] approach to the concept of presence, engagement indicates the degree to which the subjects' attention is directed to the VE, similar to when one is engrossed in a novel or movie. Immersion is the experience that one is wrapped in a surround, similar to being inside an elevator. Enjoyment is the feeling of pleasure or contentment during the VE experience. The memory test was designed as one of the contributors to presence.

To examine engagement and immersion, 9 items were developed or modified based on the well-known presence questionnaires described by Singer and Witmer [14] and by Slater, Usoh, and Steed [15]. These items were constructed based on four factors associated with the concept of presence – sensory factor (SF), distraction factor (DF), realism factor (RF), and control factor (CF) [21]. These 9 items and their associated factors were as follows. (Crayolaland is the name of the VE we used.)

1. How much did looking at Crayolaland (the VE) involve you, i.e. how much did the visual scene attract your attention? (SF)
2. To what extent did events such as noise occurring outside Crayolaland distract your attention from Crayolaland? (DF)
3. How compelling was your sense of objects moving through space? (SF, RF)
4. How consistent were experiences in the virtual environment; i.e., to what extent did you feel as though you were actually moving through Crayolaland? (SF, RF)
5. How completely were you able to actively survey or search the environment using vision? (SF, RF, CF)
6. Were you involved in the memory task to the extent that you lost track of time? (DF)
7. How much did you have a sense of "being there" in the virtual environment? (SF, RF)
8. During the time of the experience, which was strongest on the whole, your sense of being in the driving simulator room or in Crayolaland? (SF, DF, RF)
9. Structure of memory. (SF, RF, CF)

For item 9, memory structure, the score for was determined by subjects' performance on the memory test. This test was based on the postulate that people exhibit better memory structure for an environment, whether real or virtual, if they have been "in" the environment rather than simply viewing pictures of it. Previous research [18] suggests that memory structure for a VE may include the following dimensions – types, shapes, colors, relative locations, relative sizes, and event sequences. In this study, questions addressed each dimension of the subjects' VE memory structure. Each dimension included 4 different questions, one for each of the 4 trials. An example of the questions in "shape" category is shown in Figure 1. This question concerned the shapes of the mountains depicted in Crayolaland. For this example, the correct answer is "C." Some options such as "A" and "B" look similar to "C"; whereas, the other options, "D" and "E," are less similar. Therefore, for each question, the responses were categorized at three ordinal levels: "perfect, " "partial," and "poor."

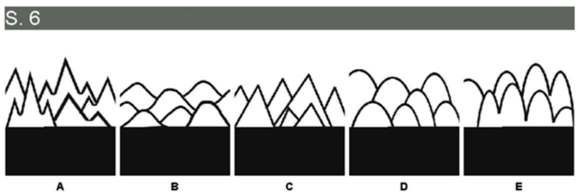

Figure 1. One example of memory questions.

The third E^2I component, enjoyment, was based a pleasure factor (PF), and satisfaction factor (TF). The five enjoyment items were as follows.

10. To what degree did you feel sad when the experience was over? (PF)
11. How much did you enjoy yourself during the experience? (PF, TF)
12. Would you like to repeat the experience you just had? (TF)
13. How interesting was your experience in Crayolaland? (PF)

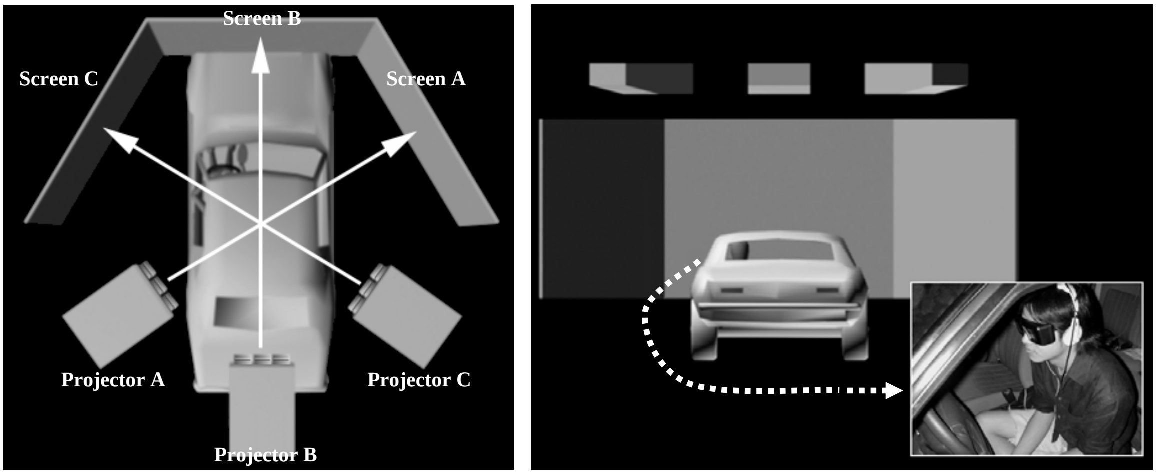

Figure 2. Equipment setting. The left figure shows the top view, and the right figure shows the back view of the setting and the close view to the subject's posture in the experiment.

14. How much would you be willing to pay to have a similar experience? (TF)

Subjects' ratings on 7-point scales for 13 of the 14 items plus the memory structure scores (item 9) were used to calculate the total E^2I score. Low scores were associated with less engagement, immersion, enjoyment, and so on. Items were weighted equally. In addition, separate subscale scores were determined for presence (items 1-8), enjoyment (items 10-14) and memory structure (item 9).

1.4 Questions and Hypothesis

Effects of FOV on responses in a VE were examined. We hypothesized that subjects' E^2I scores would increase with increasing FOV. We also hypothesized that subjects' would report more SS with increasing FOV. Regarding relationships among the E^2I scale, its subscales and SS, we hypothesized that presence and enjoyment would be positively correlated, that presence and SS would be positively correlated, and that enjoyment and SS would be negatively correlated.

2. Method

2.1 Subjects

10 subjects, 5 women and 5 men, ages 20 to 31, were recruited from the Human Interface Technology Laboratory subject pool. None reported a history of auditory disturbance, balance disorders, back problems, or high susceptibility to motion sickness. All subjects reported that they had normal or corrected vision. Subjects were paid $15 for participating in the experiment. An additional 25 cents was awarded for each correctly answered memory question. The protocol was approved by the University of Washington Human Subjects Review Committee.

2.2 Apparatus

We used a Real Drive driving simulator (Illusion Technologies International, Inc.) including a full-size Saturn car (General Motors Company), 3 800 x 600 pixel Sony Superdata Multiscan VPH-1252Q projectors, and 3 230 x 175 cm screens. A virtual world (Crayolaland) was generated by the CAVE software library (developed at the EVL, University of Illinois, Chicago) using a Silicon Graphics Onyx2 system. Crayolaland is a cartoon world that includes a cabin, pond, flowerbeds, and a forest. Additional software permitted inputs from a controller and replay of prerecorded trajectories through Crayolaland. Continuous roll axis oscillation could be added to the motion trajectory. The computer-generated images were presented on the three screens as a panoramic scene and subtended a 220º horizontal FOV. The scene was presented in stereo using CrystalEyes stereo glasses (StereoGraphics Inc.) that alternatively masked the left and right lenses. Subjects sat in the car on a balance plate that automatically calculated dispersion around the center-of-balance based on signals generated by force sensors under the plate. The experiment environment is illustrated in Figure 2.

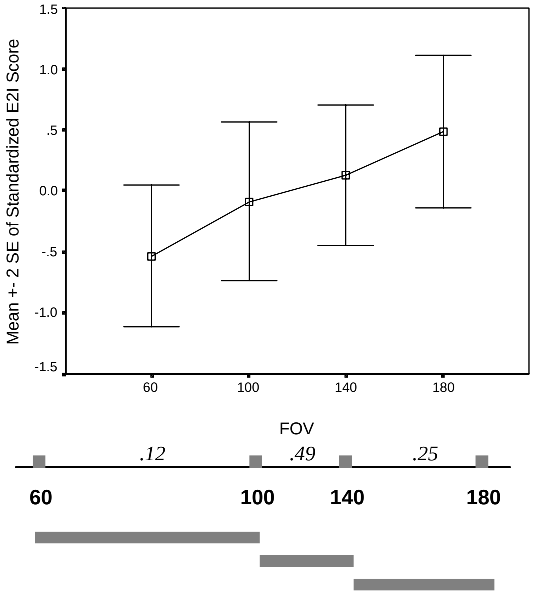

Figure 3. Mean and standard error of E^2I scores as a function of FOV.

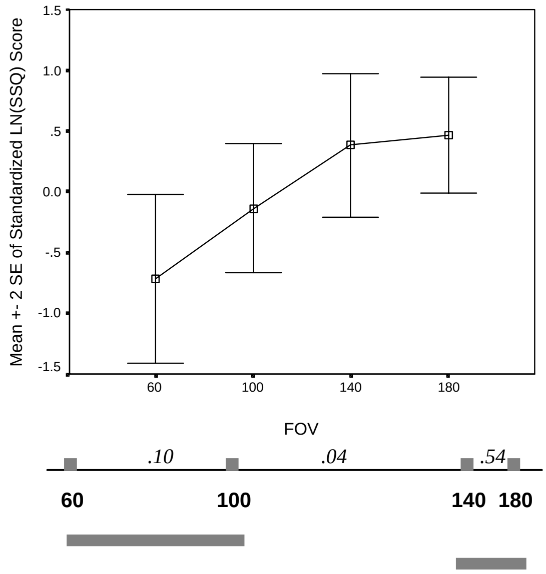

Figure 4. Mean and standard error of LN(SSQ) scores as a function of FOV.

2.3 Procedure

Subjects were "driven" through the Crayolaland VE along a quasi-circular trajectory that included left and right turns (yaw movements) as well as forward and rearward translations. A pre-recorded 120-sec trajectory around the VE was presented at each of 4 different FOVs (+/-30º, +/-50º, +/-70º, and +/-90º from the center of the visual field). All subjects experienced all 4 FOV conditions. To make the experience more provocative, continuous roll oscillation at 0.2 Hz was combined with the motion path, and stereo graphics were used. To vary the experience, 4 different starting points were selected randomly (without replacement) for the 4 FOV conditions.

The experiment sequence was as follows.

1. Instructions; pretest SSQ [9]; 2-min practice trial, during which subjects saw a motion trajectory through the VE on a desktop monitor; pre-test questionnaires including the SSQ and the E^2I questionnaire (excluding the memory structure questions).
2. Four 2-min experimental trials during which subjects were exposed to each of the 4 trajectories in each of the 4 FOV conditions. Following each trial, subjects completed the SSQ and the E^2I questionnaire (including the memory structure questions).

Each experiment took 1 to 1.5 hours. Subjects were randomly assigned, without replacement, to 1 of the 24 orders of the 4 trajectory starting points and 1 of the 24 orders of the 4 FOVs. Between trials, subjects rested for at least 5 min or until any SS symptoms associated with the previous trial had returned to baseline.

3. Results

A repeated measures multivariate analysis of variance (MANOVA) was calculated to determine the effects of FOV. Diagnostic tests for MANOVA were performed to examine the normality and homogeneity of variance assumptions on the E^2I and SSQ data. Based on the normal quantile-quantile plots, the residual plots, and the Levene's test of equality of error variances, a logarithmic transformation of the SSQ scores was performed to satisfy the assumptions of the analyses. The resulting MANOVA shows that a main effect of FOV on a linear combination of the two dependent variables, E^2I and LN(SSQ), was significant statistically [Wilks' Lambda = .032, $F(6,4) = 20.312$, $p = .006$]. Subjects' responses differed significantly across FOV levels.

Further, we analyzed FOV effects on each of the dependent variables using repeated measures univariate analysis of variance (ANOVA). These results are summarized in Figures 3 and 4. With increasing FOV, subjects exhibited increased scores for E^2I [$F(3, 27) = 5.941$, adjusted dfs = (2.022, 18.200), $p = .010$, observed power = .819] and logarithmic SSQ [$F(3, 27) = 10.598$, adjusted dfs = (1.840, 16.564), $p = .001$, observed power

= .963]. The results of post hoc analysis using the Least Significant Difference multiple comparisons method are showed in Figures 3 and 4. A bar connects those intervals *not* significantly different at the .05 level. The numbers above the bars are the p values for the adjacent intervals. The post hoc analysis for the E^2I scores showed that pairwise comparisons are significant [$p < .05$] except for all the adjacent treatment levels. For the logarithmic SSQ scores, post hoc analysis showed that all pairwise comparisons are significant [$p < .05$] except for two treatment level pairs, the 60° versus 100° and 140° versus 180°, of which the responses on 140° versus 180° are closer to each other [$p = .54$].

4. Discussion

All the data showed the same trend – with increasing FOV, subjects reported more SS as well as increased E^2I scores. The engagement and immersion components of the E^2I scale were designed to capture the concept of presence. Therefore, for the following analyses, this subscale is labeled presence. The second subscale is labeled "enjoyment." Memory task scores were included in the presence subscale and were also calculated separately.

Pearson correlation coefficients for the total E^2I scores and the presence and enjoyment subscale scores are exhibited in Table 1. SSQ scores are also included. As expected, presence and enjoyment subscale scores were positively correlated with the total E^2I scale at the 0.01 level. The two subscales were not significantly correlated, which suggests they may measure different dimensions of subjects' experience in the VE. However, further analysis suggests that the presence and enjoyment subscales may be related to one another.

Examination of relationships among the E^2I scale, its subscales and SSQ suggests an interesting model. SSQ scores were correlated positively with the presence subscale and negatively with the enjoyment subscale. Possibly, when subjects experience a sense of presence in the VE, they may also experience motion sickness or SS to a some degree. However, increasing SS may reduce enjoyment. Consequently, we see a positive correlation between presence and SS and a negative correlation between enjoyment and SS. Failure to observe a relationship between the total E^2I scores and SS may be attributed to opposing influences of SS on the presence and enjoyment subscales. Of course, distinguishing between a causal versus and a correlational relationship is difficult. Underlying structure and the cause effect relationships among SS, presence, and enjoyment should be explored in future studies.

Table 1 also shows the relationships between performance on the memory test and the other scores. The correlations between memory test scores and both the total E^2I scale and the presence subscale are highly significant. This suggests subjects may have developed better memory structure for the VE when they had a stronger sense of presence. However, the conclusion that high presence contributed to superior memory task performance may not be warranted. It has been noted previously [1,11] that information from a VE becomes more limited as FOV decreases. On the other hand, the memory task and the associated 25 cent awards for correct answers may have enhanced subjects' attention to the VE. (Subject often asked about the best previous memory test score and strove to beat that score.) To the extent that subjects became active observers of the VE, it is very likely they would be more engaged and develop a stronger senses of presence.

Table 1. Pearson Correlations of scores in E^2I scale, presence set, enjoyment set, SSQ, and memory task (n=40).

	E^2I	**Presence**	**Enjoy**	**SSQ**	**Memory**
E^2I	--	*.819***	*.482***	*.080*	*.530***
Presence	--	--	*-.109*	*.437***	*.484***
Enjoy	--	--	--	*-.527***	*.178*
SSQ	--	--	--	--	*.216*
Memory	--	--	--	--	--

** Correlation is significant at the 0.01 level (2-tailed).

The relationships shown in Table 1 suggest more refined examination of FOV effects. Effects of FOV on the presence subscale, memory scores, and the enjoyment subscale are shown in Figures 5, 6, and 7. Based on repeated measures ANOVAs, the main effect of FOV was significant for the presence subscale [$F(3, 27) = 11.910$, adjusted dfs = (2.045, 18.403), $p < .001$, observed power = .987] and memory scores [$F(3, 27) = 3.726$, adjusted dfs = (2.710, 24.391), $p = .028$, observed power = .710]. However, the main effect of FOV on enjoyment scores was not significant [$F(3, 27) = 1.093$, adjusted dfs = (1.526, 13.737), $p = .345$, observed power = .186].

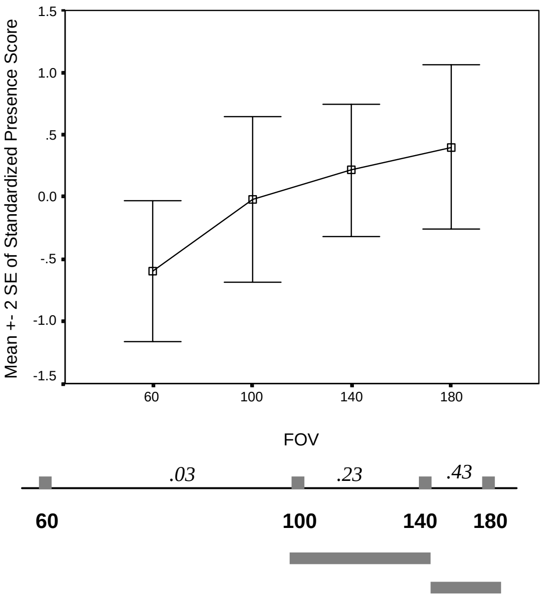

Figure 5. Mean and standard error of scores in presence subscale as a function of FOV.

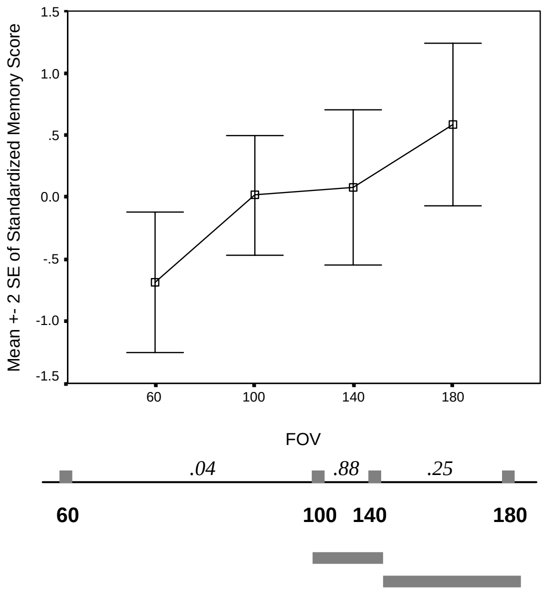

Figure 6. Mean and standard error of scores of memory task as a function of FOV.

Using the Least Significant Difference multiple comparisons method for presence subscale scores, 60° was significantly different from 100°, 140°, and 180°, and 100° was different from 180°. As shown in Figure 5, the differences between each pair of adjacent FOV intervals became smaller with increasing FOV. Comparing this result to that for logarithmic SSQ (Figure 4), both measurements indicate that responses to 140° and 180° were very similar. This suggests that subjects didn't respond differently on the presence subscale and SSQ beyond 140° FOV, although the average scores were slightly larger at 180°.

In general, sizes of changes for the dependent variables decreased with increasing FOV; i.e., the curves appeared to plateau, to reach asymptotes. This may be due in part to characteristics of human eyes. First, rod and cone receptors are distributed very differently in the retina, and different receptors mediate different visual perceptions. In terms of acuity, the all-cone fovea in the center of the retina permits high visual acuity; the rod-rich peripheral retina has lower visual acuity since the rods' convergence decreases their ability to resolve details [6,17]. Visual acuity may contribute to the sense of presence, which would be associated with the central visual field. Secondly, each eye has an individual FOV of 150° horizontally. The overlap region (binocular FOV) in the center averages 120° with 30°-35° monocular vision on each side. The combined horizontal FOV is about 180°. In this study, when the FOV levels increased beyond 120° (140° and 180°), it is likely that subjects' responses were reduced because they were mediated by monocular, non-stereo perception, even though the visual stimuli were in stereo for all experimental conditions. The trend that differences between intervals became smaller as FOV increased was also apparent for the memory scores. However, for the memory task, subjects' performance was very similar at 100°, 140°, and 180°. This may be due to the large variance for the data at 140°.

Only the enjoyment subscale failed to exhibit significant differences across FOVs (Figure 7). As shown in Table 1, the enjoyment subscale was negatively correlated with SSQ at a highly significant level [$p < .001$]. SSQ scores increased with increasing FOV. As SS became worse, it is likely that enjoyment scores would gradually decrease as shown in Figure 7. However, this relationship is neither significant nor consistent. It suggests that in addition to SS, other factors may contribute to enjoyment. One candidate may be the independent variable, FOV, itself. The effect of FOV on enjoyment should be in the direction opposite to that from SS and therefore confounded by SS. The variability of enjoyment scores may be due to the conflicting influences of SS and FOV. The change of mean enjoyment scores between 140° to 180° provides a clue to a possible confounding effect. Although SSQ scores at 140° and 180° were nearly the same, the mean enjoyment scores exhibited a large and somewhat puzzling increase across this interval.

Basically, the results support our hypotheses regarding FOV effects on E^2I and SSQ scores. E^2I scores increased with increasing FOV. However, not all of the subscales exhibited this effect significantly. The positive correlation between the presence subscale and FOV confirmed previous research described in Section 1.2. The enjoyment subscale, however, failed to exhibit a significant difference across FOV, although the data suggest a complex relationship between FOV and enjoyment, as discussed above. The negative correlation between SS and FOV supported our hypothesis as well as results from previous studies [7, 10, 12].

The results supported our hypotheses of a positive correlation between presence and SS and a negative one between enjoyment and SS. However, a significant correlation between presence and enjoyment was not found. This differs from the study by Nichols et al. [12] and may be due to differences in the subjects' tasks in the two studies. In their study, subjects searched for blocks in a virtual room and placed them in defined locations; whereas, subjects in our study sat in a car and acted as observers performing the memory task instead of actively "driving" the car on their own. It is very likely that the feeling of enjoyment in a highly interactive VE, such as that used by Nichols et al. would be stronger than in a low interactive VE, such as the one we used. Further, it may be that SS symptoms reported by subjects in a highly interactive VE would be less because of their greater involvement and excitement. This suggests an interesting avenue for our future research - exploring the effects of interactivity in VEs. We suggest relationships among presence, enjoyment, and SS may be significantly changed under different levels of interactivity.

All 14 items of the E^2I scale were weighted equally for the analyses in this study. As these items may measure heterogeneous dimensions for the concepts of presence and enjoyment, factor analysis will be performed to identify possible underlying dimensions in the measurement scales when the size of the data set permits.

5. Conclusion

A refined scale to assess users' experiences in VEs was developed. The E^2I included presence and enjoyment subscales as well a memory structure test. This scale was evaluated by examining effects as a function of varying FOV in the VE. Relationships between total E^2I scale scores, presence and enjoyment subscale scores, and scores from the SSQ were examined.

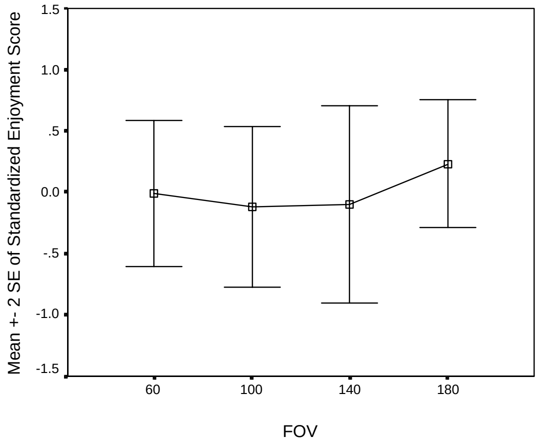

Figure 7. Mean and standard error of scores in enjoyment subscale at different FOVs.

The results from this experiment indicated that presence enjoyment, and SS varied as a function of display FOV. Subjects exhibited higher SSQ and presence subscale scores with increasing FOV. Sizes of changes of effects on presence and SS decreased with increasing FOVs. Differences for FOVs beyond 140° were small.

This study suggested a positive correlation between presence and SS and a negative one between enjoyment and SS. The correlation coefficients for the presence subscale and SSQ as well as for the enjoyment subscale and SSQ were highly significant. In addition, the study revealed a positive correlation between performance on memory structure test and presence scores. The main effect of FOV was also significant for the memory task scores. Complete understanding of the underlying model and possible causal relationships among SS, presence, and enjoyment requires further research.

Acknowledgments

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