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Research paper

The Study of Side Coordinate's Function and Effective Application Plan to Reduce Cyber-Sickness in Driving Simulation

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Abstract

Background/Objectives: We focused on objects around player as another element to reduce "Cyber-sickness", which has been treated as serious problem in VR research. Therefore, we defined these objects as "Side Coordinate".
Methods/Statistical analysis: We constructed several environments for experiment with different standards based on the cognitive speed formula to discover correlation between side coordinate and cyber-sickness. 30 subjects in their 20s participated in the experiment and we surveyed them with SSQ(Simulator sickness Questionnaire) to analyze whether they felt cyber-sickness. We also examined 3 main elements of cyber-sickness to find out which one has the greatest effect on the sickness.
Findings: The results of the survey were analyzed by One-way ANOVA and 'Scheffe' method for the 'Post Hoc' test in SPSS program was used for detail information. According to the results in the experiment, we found side objects caused more cyber-sickness when distance between objects and player, which is called "Side Distance" becomes too far. Not only side distance, but distance between objects, which is called "Object Distance" also caused the disorientation in the analysis of 3 components, which are nausea, oculomotor, and disorientation that constitute cyber-sickness. When side distance and object distance were set to the shortest distance, subjects felt disorientation. Especially, long side distance caused the worst disorientation problem based on statistical analysis. It can be deduced that a disturbance between visual and vestibular information occurs due to the difference between the actual speed and the cognitive speed, resulting in cyber-sickness. And we can infer that disorientation is the main factor in cyber-sickness among 3 elements.
Improvements/Applications: Lastly, using cognitive speed formula to get proper distance between side objects could help VR developer match the actual speed and perceptual speed to prevent cyber-sickness.

Keywords: *Side Coordinate, VR, Cyber-Sickness, Driving Simulation, SSQ, Cognitive Speed Formula*

1. Introduction

People could experience virtual reality contents easily since HMD has been generalized these days, and even if they don't have HMD, it's also possible to use various VR equipments in VR café. However, virtual motion sickness called "Cyber-Sickness" is one of the most serious problems, which has been discussed in almost VR contents research and discussion[1]. Main reason for cyber-sickness is the mismatch between visual information and one's expectation[2,3]. Many researches proved that using "Rest Frame" can help to reduce cyber-sickness. Rest frame is a stable element like background/context/ground in the real world[3]. If a player moves in the virtual world, rest frame becomes a standard to let player judge their movement. Reducing the size of FOV(Field Of View) can also help cyber-sickness problem[4]. If the size of FOV becomes bigger, it induces more vection and eventually, conflict between visual information and vestibular system could get worse. In addition, when developing the VR contents, the more main events appeared in front of player's view, the less dizziness and cyber-sickness become occurred[5].Though the objects located on the sides of the viewport is one of the most stick out elements in view, its guideline has not been proposed clearly. In this paper, we researched the influence of side object on cyber-sickness in fast virtual driving environment, and defined new standard called "Side Coordinate".

2. Experimental Environment

2.1. Previous Research

Based on the 『The VR Book』, there are two big reasons caused cyber-sickness and "Sensory Conflict Theory" is one of those big reasons[3]. When people are moving in the real world, visual information exactly matches vestibular information, which is sense of balance and spatial orientation. However, when people play VR contents, players only get visual information from the virtual world, while they still get vestibular information from real world. Therefore, cyber-sickness become caused by the mismatch between the two information.

"Rest Frame Hypothesis" indicates that the cyber-sickness provoked from the difference between visual information and brain information. Brain recognizes stationary objects and makes the basic standard called "Rest Frame" to judge movement of

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oneself or other objects. If new movements don't match with the rest frame, cyber-sickness induced[3].

In this research, we used SSQ(Simulator Sickness Questionnaire) before and after each experiment to find out whether subjects feel cyber-sickness or not under certain environment[6]. SSQ is to judge motion-sickness by various questions consist of 3 sections. Since road object and side coordinates could become standards for the direction information, we supposed "Disorientation" would have very little impact compared to other 2 sections, "Nausea" and "Oculomotor" in this experiment. Table 1 is the 16 SSQ questions. Each question was decided by subject's body condition and by calculation the question score, we could figure out if subject felt cyber-sickness[7].

Table 1: SSQ questions classified with 3 compositions

Nausea	Oculomotor	Disorientation
General Discomfort		
	Fatigue	
	Headache	
	Eyestrain	
	Difficulty focusing	
Increased salivation		
Sweating		Sweating
Nausea		
Difficulty Concentrating		
		Fullness of Head
	Blurred Vision	
		Dizzy (eye open)
		Dizzy (eye closed)
		Vertigo
Stomach Awareness		
Burping		

While searching for the other researches regarding side objects, we found one paper about correlation between velocity perception and graphic module in driving simulation, and proposed factors related to velocity perception in VR environment[8]. In their research, subjects conducted a simulation to acknowledge the absolute velocity before the experiment. Then they separated the side object element by 2 factors, "Lateral distance" and "Texture width". Through the experiments, they found the formula for cognitive speed depends on two factors.

$$= 1.6\, V_a * y^{-0.32}$$

$(V_p : \text{cognitive speed}, V_a : \text{driving speed}, y : \text{side distance})$

Cognitive speed formula depends on lateral distance

$$V_p = 1.34\,(\,0.85V_a + 4.1\,)\,d^{-0.176}$$

$(V_p : \text{cognitive speed}, V_a : \text{driving speed}, d : \text{texture width})$

Cognitive speed formula depends on texture width

Referring to "Sensory Conflict Theory" and "Rest Frame Hypothesis", we used VR simulator to mimic vehicle movement in real world[3]. A virtual infinite environment and a virtual vehicle with physics for realistic behavior of car were also developed for the experiment. Then we decided 2 components of side coordinate based on two cognitive speed formulas. Table 2 shows the components of side coordinate and its definition.

Table 2: 2 Components of Side Coordinate

The elements of side coordinate	Definition
Side Distance	Distance from the middle of the road to object
Object Distance	Distance between objects

Instead of lateral distance and texture width, we define "Side Distance" and "Object Distance" for side coordinate's elements. Side distance is the length from middle of the road to side object. Object distance is the space between each object. Distance was measured not from the middle of side object, but the end point of object boundary. Therefore, side objects position became decided based on side and object distance. Correlation between side coordinate and cyber-sickness was compared to cognitive speed formula[8,9]. Experimental environment built for figure out the correlation between those elements and cyber-sickness as seen in Figure 1.

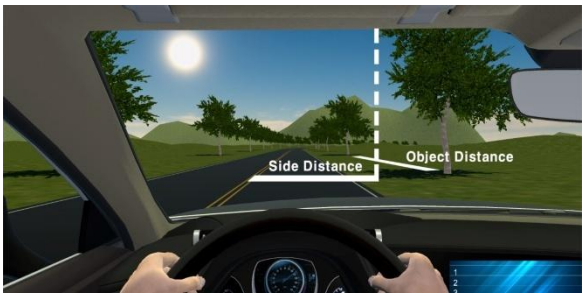


Figure 1:.2 Side coordinate's components in VR Environment

2.2. Experimental Inspectors Settings

In order to set up standard for experiment, we used cognitive speed formulas to find out length of side distance and object distance where real driving speed matches with cognitive speed. Since our car's maximum speed is 100km/h, cognitive speed matches with the real speed when the side distance is set to 6mand object distance is 5.6m. To figure out the correlation between cognitive speed and cyber-sickness, two side coordinate's elements' inspector was divided in 3 units. Distance calculated by formula was set to medium distance unit. Then one of other two units was shorter than medium distance, and the other one was longer than medium distance. Especially, we set object distance as medium while side distance experiment became conducted to exclude cyber-sickness influenced by object distance. For the same reason, side distance was set to medium when experiment was conducted for object distance. Figure 2 and Figure 3 shows the experimental environments designed to figure out correlation between side coordinate and cyber-sickness.

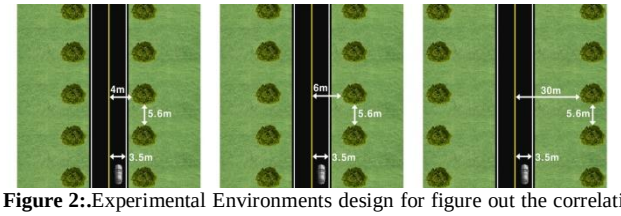


Figure 2:. Experimental Environments design for figure out the correlation between Side Distance and cyber-sickness

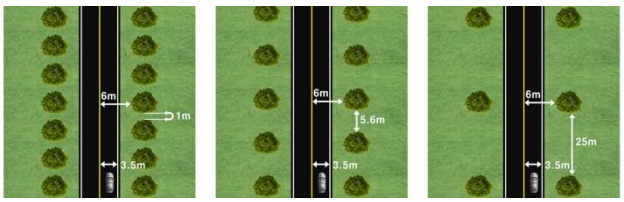


Figure 3:. Experimental Environments design for figure out the correlation between Object Distance and cyber-sickness

2.3. Experiment Process

To minimize the impact of other causes of cyber-sickness, we set the experimental environment as wide field to exclude any environmental element to cause c, and also surrounded by static mountain

We set a default background in experimental environment as wide field, so it would be difficult for players to set a standard for

perceiving speed if there is no object on side of the road. A static mountain also was surrounded the field as one of rest frame, since we needed an environment that minimizes the influence of other causes of cyber-sickness. This mountain object always came into the viewport, so it performed like a distant background object in the real world. Road lane width was set by 3.5m based on Korean standard to increase the sense of reality and the road was set 2 lane-roads[10]. Maximum driving speed was limited by 100km/h. For side object, we used tree objects to reduce the sense of incompatibility. Subjects could drive a car in VR using HTC VIVE and Logitech G29 driving force racing wheel.

30 subjects in their 20s have participated in the experiment. In order to make survey result more detail, we used seven-point scale in SSQ and subjects were examined by a survey before the experiments and we surveyed them again after the experiments to compare between pre- and post-condition. In order to prevent the influence of previous experiment, subjects had enough time to rest between each experiment.

3. Experiment Result

After several experiments, 6 subjects' inappropriate results out of 30 subjects were excluded from the statistical analysis. We analyzed the effect of side coordinate's elements on the total SSQ score, nausea, oculomotor, and disorientation using One-way ANOVA by SPSS version 25. In the result, we got 3 significant results among the all 8 ANOVA results. Figure 4 is the result of One-way ANOVA conducted to compare effect of side distance on the total SSQ score.

Oneway

Descriptives

Total_SSQ_Score

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Ordinary	24	123.5758	33.18654	6.77417	109.5624	137.5893	78.54	194.48
Short distance_4m	24	156.7683	46.42419	9.47630	137.1651	176.3715	86.02	280.50
Normal distance_6m	24	143.5225	39.23805	8.00943	126.9537	160.0913	82.28	201.96
Long distance_30m	24	160.1967	49.08269	10.01896	139.4709	180.9225	82.28	239.36
Total	96	146.0158	44.19540	4.51067	137.0610	154.9707	78.54	280.50

ANOVA

Total_SSQ_Score

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	19835.582	3	6611.861	3.671	.015
Within Groups	165721.588	92	1801.322		
Total	185557.170	95			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Total_SSQ_Score

Scheffe

(I) Side_Distance	(J) Side_Distance	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Ordinary	Short distance_4m	-33.19250	12.25194	.069	-68.0853	1.7003
	Normal distance_6m	-19.94667	12.25194	.453	-54.8395	14.9462
	Long distance_30m	-36.62083*	12.25194	.036	-71.5137	-1.7280
Short distance_4m	Ordinary	33.19250	12.25194	.069	-1.7003	68.0853
	Normal distance_6m	13.24583	12.25194	.761	-21.6470	48.1387
	Long distance_30m	-3.42833	12.25194	.994	-38.3212	31.4645
Normal distance_6m	Ordinary	19.94667	12.25194	.453	-14.9462	54.8395
	Short distance_4m	-13.24583	12.25194	.761	-48.1387	21.6470
	Long distance_30m	-16.67417	12.25194	.605	-51.5670	18.2187
Long distance_30m	Ordinary	36.62083*	12.25194	.036	1.7280	71.5137
	Short distance_4m	3.42833	12.25194	.994	-31.4645	38.3212
	Normal distance_6m	16.67417	12.25194	.605	-18.2187	51.5670

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

Homogeneous Subsets

Total_SSQ_Score

Scheffe[a]

Side_Distance	N	Subset for alpha = 0.05: 1	2
Ordinary	24	123.5758	
Normal distance_6m	24	143.5225	143.5225
Short distance_4m	24	156.7683	156.7683
Long distance_30m	24		160.1967
Sig.		.069	.605

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24.000.

Figure 4:. Result of One-way ANOVA with Side Distance Experiment's Total SSQ Score

The effect of side distance on the total SSQ score was significant, $F(3, 92) = 3.671$, $p = .015$. By Post Hoc Tests using 'Scheffe' method, there was a significant difference between ordinary condition and long side distance ($p = .036$) environment. This means that subjects felt cyber-sickness when the side object was set to 30m from center of the road. Total SSQ score of experiments related to object distance didn't show the significant ANOVA result. To find out which SSQ elements influence on total SSQ score more significantly, we conducted One-way ANOVA with side coordinate's elements on each 3 SSQ elements score.

Oneway

Descriptives

Total_SSQ_Score

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Ordinary	24	147.3200	41.43935	8.45877	129.8217	164.8183	97.44	250.56
Short distance_4m	24	198.3600	68.10108	13.90107	169.6034	227.1166	97.44	375.84
Normal distance_6m	24	175.7400	48.36204	9.87186	155.3185	196.1615	97.44	264.48
Long distance_30m	24	202.4200	63.45566	12.95283	175.6250	229.2150	97.44	306.24
Total	96	180.9600	59.71015	6.09414	168.8616	193.0584	97.44	375.84

ANOVA

Total_SSQ_Score

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	46132.550	3	15377.517	4.836	.004
Within Groups	292571.117	92	3180.121		
Total	338703.667	95			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Total_SSQ_Score

Scheffe

(I) Side_Distance	(J) Side_Distance	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Ordinary	Short distance_4m	-51.04000*	16.27913	.025	-97.4020	-4.6780
	Normal distance_6m	-28.42000	16.27913	.389	-74.7820	17.9420
	Long distance_30m	-55.10000*	16.27913	.013	-101.4620	-8.7380
Short distance_4m	Ordinary	51.04000*	16.27913	.025	4.6780	97.4020
	Normal distance_6m	22.62000	16.27913	.589	-23.7420	68.9820
	Long distance_30m	-4.06000	16.27913	.996	-50.4220	42.3020
Normal distance_6m	Ordinary	28.42000	16.27913	.389	-17.9420	74.7820
	Short distance_4m	-22.62000	16.27913	.589	-68.9820	23.7420
	Long distance_30m	-26.68000	16.27913	.447	-73.0420	19.6820
Long distance_30m	Ordinary	55.10000*	16.27913	.013	8.7380	101.4620
	Short distance_4m	4.06000	16.27913	.996	-42.3020	50.4220
	Normal distance_6m	26.68000	16.27913	.447	-19.6820	73.0420

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

Homogeneous Subsets

Total_SSQ_Score

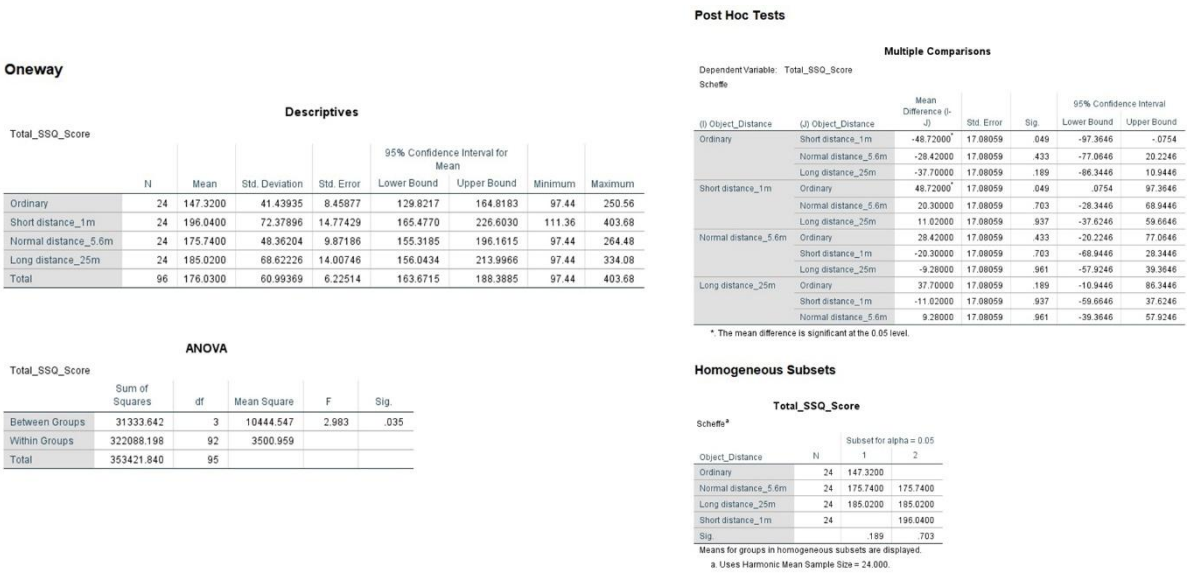
Scheffe[a]

Side_Distance	N	Subset for alpha = 0.05: 1	2
Ordinary	24	147.3200	
Normal distance_6m	24	175.7400	175.7400
Short distance_4m	24		198.3600
Long distance_30m	24		202.4200
Sig.		.389	.447

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24.000.

Figure 5:. Result of One-way ANOVA with Side Distance Experiment's Disorientation Score



Oneway

Descriptives

Total_SSQ_Score

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Ordinary	24	147.3200	41.43935	8.45877	129.8217	164.8183	97.44	250.56
Short distance_1m	24	196.0400	72.37896	14.77429	165.4770	226.6030	111.36	403.68
Normal distance_5.6m	24	175.7400	48.36204	9.87186	155.3185	196.1615	97.44	264.48
Long distance_25m	24	185.0200	68.62226	14.00746	156.0434	213.9966	97.44	334.08
Total	96	176.0300	60.99369	6.22514	163.6715	188.3885	97.44	403.68

ANOVA

Total_SSQ_Score

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	31333.642	3	10444.547	2.983	.035
Within Groups	322088.198	92	3500.959		
Total	353421.840	95			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Total_SSQ_Score

Scheffe

(I) Object_Distance	(J) Object_Distance	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Ordinary	Short distance_1m	-48.72000*	17.08059	.049	-97.3646	-.0754
	Normal distance_5.6m	-28.42000	17.08059	.433	-77.0646	20.2246
	Long distance_25m	-37.70000	17.08059	.189	-86.3446	10.9446
Short distance_1m	Ordinary	48.72000*	17.08059	.049	.0754	97.3646
	Normal distance_5.6m	20.30000	17.08059	.703	-28.3446	68.9446
	Long distance_25m	11.02000	17.08059	.937	-37.6246	59.6646
Normal distance_5.6m	Ordinary	28.42000	17.08059	.433	-20.2246	77.0646
	Short distance_1m	-20.30000	17.08059	.703	-68.9446	28.3446
	Long distance_25m	-9.28000	17.08059	.961	-57.9246	39.3646
Long distance_25m	Ordinary	37.70000	17.08059	.189	-10.9446	86.3446
	Short distance_1m	-11.02000	17.08059	.937	-59.6646	37.6246
	Normal distance_5.6m	9.28000	17.08059	.961	-39.3646	57.9246

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

Homogeneous Subsets

Total_SSQ_Score

Scheffe[a]

Object_Distance	N	Subset for alpha = 0.05	
		1	2
Ordinary	24	147.3200	
Normal distance_5.6m	24	175.7400	175.7400
Long distance_25m	24	185.0200	185.0200
Short distance_1m	24		196.0400
Sig.		.189	.703

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24.000.

Figure 6:. Result of One-way ANOVA with Object Distance Experiment's Disorientation Score

Among the 3 SSQ elements, disorientation shows the significant result on both side distance ($F(3, 92) = 4.836$, $p = .004$) and object distance ($F(3, 92) = 2.983$, $p = .035$) in Figure 5 and Figure 6. Subjects felt disorientation when side distance was set to 4m ($p = .025$) and 30m ($p = .013$). This symptom also occurred when object distance was set to 1m ($p = .049$). By comparing those significant values, long side distance became the main reason that causes disorientation. Moreover, due to the total SSQ score of long side distance had significant value, disorientation seems to be strongly related with cyber-sickness.

4. Conclusion

According to the result of experiments, we figured out side distance was a very important factor that causes cyber-sickness. If side objects become too far from the player, it will arouse the VR sickness and disorientation problem. We also found there was a significant correlation between side/object distance and disorientation. We assumed that difference in distance between objects(or between objects and player) affects player's cognitive speed and if there is any incongruity between actual speed and cognitive speed, it caused the disorientation problem. Due to this disorientation can cause the serious cyber-sickness problem, side coordinate has to be set proper distance to reduce those problem. Using cognitive speed formula could help VR developer get side coordinate's optimum distance and prevent the cyber-sickness problem. Especially, if the VR contents force players to move very fast, it could bring the serious sickness problem. Therefore, proper distance of side coordinate would be very important factor for contents development. Scale, color and shape complexity of side objects were not included in this research, but those attributes should be handled in further research, since we assumed that they also might have correlation with cyber-sickness.

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