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A NEW PROCEDURE FOR MEASURING SIMULATOR SICKNESS – THE RSSQ

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ABSTRACT

The purpose of this study was to develop and test a new tool for quantitatively measuring simulator sickness (SS). The widely used Simulator Sickness Questionnaire (SSQ) has some limitations. A new Revised Simulator Sickness Questionnaire (RSSQ) was developed to supplement and extend the original SSQ. For this study, we reduced the 31 SSQ symptoms to 24 symptoms and developed weighted values for each symptom using a group of 15 SS experts. The RSSQ was administered to 64 subjects before and after exposure to virtual reality (VR) in a driving simulator. The resulting data were evaluated using factor analysis. Four major symptom types were identified: Disorientation, Oculomotor, Nausea, and Strain/Confusion. The scoring system for the RSSQ provides sub-scale scores each of these four symptom types as well as a total severity score. Because the SSQ and RSSQ use similar symptoms, the present study can be interpreted as partially replicating and validating the SSQ using a different population – Asian, non-pilot civilians. The new factor - Strain/Confusion – may result from inclusion of several new symptoms in the RSSQ and / or may reflect cultural differences between Korean and United States participants. The relative ease of comparing repeated exposures to a VR system using the RSSQ may be useful for the within-subjects experimental designs that are common in VR research.

1.0 INTRODUCTION

Questionnaires or symptom checklists are commonly used for assessing SS. Measuring just one sign or symptom would not be adequate because of the poly-symptomatic nature of SS (Kennedy & Fowlkes, 1992). One frequently used questionnaire is known as the Pensacola Motion Sickness Questionnaire (MSQ; Kellogg, Kennedy, & Graybiel, 1965). This questionnaire is a self-report form consisting of 23 symptoms that are rated by the subject on a 4-point severity scale (none, mild, moderate, severe). Although the scoring system of the MSQ assesses several symptoms, a major limitation in its application to SS is that the resulting scores provide no information to distinguish the several dimensions of the sickness (Kennedy & Fowlkes, 1992). This limitation led to the development of the SSQ (Kennedy, Lane, Berbaum, & Lilienthal, 1993).

The SSQ was derived from the MSQ using factor analysis of 1,119 MSQs collected at 10 simulator sites. The SSQ reduced the symptom list to 16 symptoms, all of which are rated by the subject on a 4-point scale (0 - absent, 1 - slight, 2 - moderate, 3 - severe). Based on the results of factor analysis, these ratings formed the basis for the three sub-scale scores, Nausea, Oculomotor Disturbance and Disorientation, as well as a Total Severity score. Symptoms associated with the three sub-scale scores are: Nausea - general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, and burping; Oculomotor - general discomfort, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating, and blurred vision; and Disorientation - difficulty focusing, nausea, fullness of head, blurred vision, dizzy (eyes open), dizzy (eyes closed), and vertigo (Kennedy et al., 1993). (Note that some symptoms contribute to more than one subscale; this is a characteristic of the factor analysis procedure.) The Total Severity score is based on all of the symptoms.

Although widely and successfully used, Kim, Park, & Yi (1998) suggested that the SSQ could be improved by addressing several issues. First, there are some symptoms not included in the SSQ that may be indicative of SS and have serious effects on the human physiology and performance in a simulator. Second, all SSQ symptoms were treated equally with weighting values of 0 or 1. Third, the original SSQ subjects were young, well-trained pilots. If members of the general population had been subjects for the original SSQ research, the results could have been different. Fourth, the SSQ scoring system did not consider

subjects' baseline physiological condition. In order to isolate effects caused by a virtual environment (VE) or simulator, it is useful to compare pre- and post-exposure scores, which the original SSQ did not do. Kennedy et al. (1993) suggested that there was no problem in assuming that none of their subjects had SS symptoms prior to exposure because they were all healthy military personnel. However, if the subjects had been drawn from the general population, pre-exposure physiological conditions would likely have varied, which supports the suggestion that pre- and post-exposure SS scores should be compared. Also, because each symptom of the SSQ is rated on a 4-point ordinal scale (0 - nothing, 1 - mild, 2 - moderate, 3 - severe), it is not easy to subtract the pre-exposure SSQ scores from the post-exposure scores. Fifth, although the SSQ symptoms were selected from the 28 symptoms of the MSQ, the MSQ does not include some symptoms that have been related to SS, e.g., facial pallor, ataxia and so on. Moreover, there are some symptoms that are related to SS included in the MSQ but excluded from the SSQ even though these symptoms are indicative of SS. Vomiting is an example. Kennedy et al. (1993) explained that vomiting was omitted from the SSQ because only 2 out of 1,200 of their subjects actually vomited. However, if the subjects had been from a general population instead of pilots, the vomiting incidences probably would have been higher. In fact, when Yi, Park, Oh and Kim (1997) observed 150 general-population subjects, 2 vomited. To address these concerns, the RSSQ was developed.

2.0 RSSQ: SYMPTOMS AND WEIGHTS

Initial development of the RSSQ followed the same process by which the original SSQ was developed. The final RSSQ and the scoring system were based on data from an empirical study.

2.1 Basic Questionnaire

The basic questionnaire included the original 28 MSQ symptoms and 3 symptoms described in other studies (Kennedy & Fowlkes, 1992; Yi et al., 1997). This questionnaire was used for selecting RSSQ symptoms (see Section 2.3).

Weights were assigned to each symptom based on ratings by a group of specialists who were familiar with motion and simulator sickness (Section 2.4). Table 1 lists the initial RSSQ symptom set.

Table 1. Symptoms used in initial questionnaire

SYMPTOMS	Included in MSQ	Included in SSQ
1. General discomfort	○	○
2. Fatigue	○	○
3. Boredom	○	
4. Drowsiness	○	
5. Headache	○	○
6. Eye strain	○	○
7. Difficulty focusing	○	○
8. Increased salivation	○	○
9. Decreased salivation	○	
10. Sweating	○	○
11. Nausea	○	○
12. Diff. concentrating	○	○
13. Depression	○	
14. Fullness of head	○	○
15. Blurred vision	○	○
16. Dizzy (EO)	○	○
17. Dizzy (EC)	○	○
18. Vertigo	○	○
19. Visual flashbacks	○	
20. Faintness	○	
21. Awareness of breathing	○	
22. Stomach awareness	○	○
23. Decreased appetite	○	
24. Increased appetite	○	
25. Desire to move bowels	○	
26. Confusion	○	
27. Burping	○	○
28. Vomiting	○	
29. Facial pallor		
30. Difficulty equilibrating		
31. Muscle stiffness from strain		

2.2 Specialist Panel

A group of 15 SS specialists from 3 different areas was selected for this research. The group included the operator crew for a simulator, a team of developers for that simulator, and a group of medical and academic researchers. This specialist group selected the final RSSQ symptom set and assigned weights to each symptom according to that symptom's relative importance.

2.3 Symptom Selection

The 15 specialists were individually interviewed using the basic questionnaire presented in Table 1. From the list of 31 symptoms, the specialists were first asked to select those symptoms that they thought were most indicative of SS, including those that they had observed in their own work. Table 2 shows number of specialists who identified each symptom as indicating SS. The 24 symptoms included in the final RSSQ were chosen by at least 6 of the 15 specialists. Note that the 16 symptoms employed in the SSQ are included in Table 2. The 8 symptoms in the RSSQ but not in the SSQ include drowsiness, visual flashbacks, awareness of breathing, confusion, vomiting, pallor, difficulty equilibrating, and muscle stiffness from strain. The RSSQ includes 3 symptoms that were not part of the MSQ: pallor, difficulty equilibrating, and muscle stiffness from strain. Pallor and difficulty equilibrating have been noted as indicative of SS in many other studies (Kennedy and Fowlkes, 1992; Casali and Wierwille, 1986; Baltzley,

Kennedy, Berbaum, Lilienthal, & Gower, 1989). Muscle stiffness from strain was observed by Yi et al. (1997).

Table 2. Symptom selection by specialists

Symptoms	No. of 15 specialists who selected symptom	Included in RSSQ	Included in SSQ
1. General discomfort	12	○	○
2. Fatigue	11	○	○
3. Boredom	5		
4. Drowsiness	9	○	
5. Headache	13	○	○
6. Eye strain	14	○	○
7. Difficulty focusing	14	○	○
8. Increased salivation	6	○	○
9. Decreased salivation	2		
10. Sweating	11	○	○
11. Nausea	14	○	○
12. Diff. concentrating	14	○	○
13. Depression	1		
14. Fullness of head	11	○	○
15. Blurred vision	11	○	○
16. Dizzy (EO)	9	○	○
17. Dizzy (EC)	10	○	○
18. Vertigo	13	○	○
19. Visual flashbacks	11	○	
20. Faintness	5		
21. Awareness of breathing	8	○	○
22. Stomach awareness	11	○	
23. Decreased appetite	5		
24. Increased Appetite	0		
25. Desire to move bowels	0		
26. Confusion	9	○	
27. Burping	6	○	○
28. Vomiting	14	○	
29. Pallor	13	○	
30. Difficulty equilibrating	10	○	
31. Muscle stiffness for strain	9	○	

2.4 Symptom Weights

The specialists were questioned a second time about the relative influence of each of the 24 selected RSSQ symptoms according to the importance each might have physiologically as well as for operation of the simulator. Following a magnitude estimation paradigm, the specialists could choose any number (excluding 0 or negative numbers) to indicate the importance of a symptom relative to the standard symptom of general discomfort (modulus). For instance, if the nausea were determined to be 10 times more important than the standard discomfort symptom, which was arbitrarily assigned a value of 10, then the weight for nausea would be 100. If the importance of nausea were 0.5 of the standard symptom, then the assigned weight would be 5.

Table 3 shows the geometric means and the normalized weighted values of the geometric means for each symptom's importance based on the specialists' evaluations. The geometric mean was chosen to calculate normal weighted values because the geometric mean is influenced less by extreme values than the arithmetic mean. Also, the geometric mean is more appropriate to use in calculating the relative ratios or changes. Vomiting is the most heavily weighted symptom followed by nausea and then vertigo, as shown in Table 3.

Table 3. Geometric Means and Normalized Weighted Values for RSSQ Symptom Set

SYMPTOMS	Geometric Mean	Normalized weights
1. General discomfort	10	0.00932
2. Fatigue	13.34	0.01244
3. Drowsiness	4.83	0.00450
4. Headache	44.38	0.04137
5. Eye-strain	49.28	0.04594
6. Difficulty focusing	46.1	0.04297
7. Increased salivation	6.45	0.00602
8. Sweating	15.4	0.01435
9. Nausea	98.65	0.09195
10. Diff. concentrating	36.38	0.03391
11. Fullness of head	31.21	0.02909
12. Blurred vision	33.61	0.03132
13. Dizzy (EO)	73.46	0.06847
14. Dizzy (EC)	63.59	0.05927
15. Vertigo	90.4	0.08426
16. Visual flashbacks	36.6	0.03412
17. Awareness of breathing	33.58	0.03130
18. Stomach awareness	34.63	0.03228
19. Confusion	18.93	0.01765
20. Burping	6.68	0.00622
21. Vomiting	190.82	0.17786
22. Pallor	38.32	0.03572
23. Difficulty equilibrating	61.33	0.05716
24. Muscle stiffness from strain	34.89	0.03252
Total		1.00000

3.0 RSSQ: CONSTRUCTION AND SCORING

This section describes development of the RSSQ using the 24 symptoms listed in Table 3. The RSSQ employs an 11-point scale (0 - nothing, 10 - very severe) instead of the 4-point ordinal scale used in the SSQ. Figure 1 shows an example of the RSSQ scale.

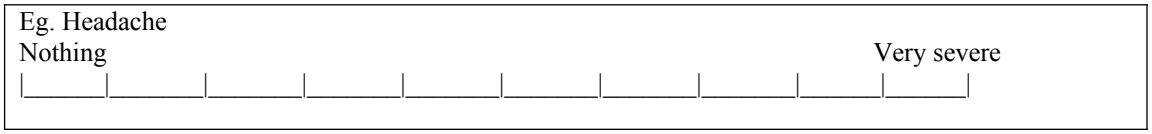

Figure 1. Example of symptom rating scale

3.1 Data collection: a simulator experiment

56 men and 8 women (ages 22 – 35) were exposed to a motion simulation in a driving simulator twice each. A minimum of 3 days elapsed between exposures. A total of 128 pre-exposure and 128 post-exposure RSSQs were collected.

The fixed-based driving simulator used for this experiment was a model SSDS-V1 that was developed by Ssang-Yong Information and Communication Inc. (Figure 2). The driving simulator dimensions were 220 cm length, 125 cm width, and 150 cm height. The interior of the simulator was identical to the driver's seat of a mid-size sedan that is sold internationally, and a 24 inch computer monitor presented the scene in front of the car. A 3-D computer graphics program that used the Open GL (Graphics Library) generated the visual display. The spatial resolution of this visual system was 640 x 480 pixels. Temporal resolution was 13 frames per sec.

The simulation required the subject find his/her way to Kimpo International Airport from a designated point. There were 10 different scenarios for potential accidents during the course of the simulation; therefore, the driver had to drive carefully to avoid accidents. The running time for the simulation was 15-20 min. The RSSQ data were collected before and after each trial. Comparison of pre-exposure with post-exposure RSSQ data permitted identification of symptoms associated with simulator exposure.

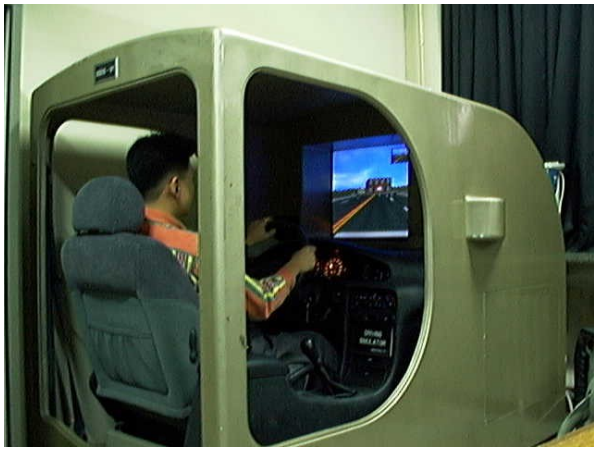

Figure 2. Fixed-based driving simulator (SSDS-V1)

3.2 Factor analysis

This analysis was done to facilitate better understanding of SS complexity and to determine underlying symptom groupings. The 128 RSSQ data sets (pre- and post-exposures) were evaluated by factor analysis. Four factors were identified. Varimax rotation of the factors was performed in order to determine loading values for each symptom. Each factor included eight symptoms that had moderate to high loadings of 0.4 (Varimax loading reference value) or greater.

Table 4 shows the results of this factor analysis. The first factor included symptoms related to disorientation, the second included symptoms related to ocular discomfort, and the third factor consisted of symptoms related to nausea. The fourth factor was unexpected and consisted of symptoms related to nervousness, strain and confusion. Factor 1 is labeled “nausea;” Factor 2 as “disorientation;” and Factor 3 as “ocular discomfort.” Factor 4 included a group of symptoms that we label “strain/confusion.”

Table 4. Varimax Factor Loading Values for Each Symptom

SYMPTOMS	Factor 1	Factor 2	Factor 3	Factor 4
18. Stomach awareness	.80*	.07	.30	.20
9. Nausea	.77*	.29	.28	.27
7. Increased salivation	.74*	.37	.23	.16
21. Vomiting	.72*	.32	-.04	.21
20. Burping	.70*	.31	.36	.24
17. Awareness of breathing	.69*	.11	.21	.24
8. Sweating	.46*	.32	.20	.42*
13. Dizzy (EO)	.24	.86*	.20	.17
14. Dizzy (EC)	.24	.85*	.23	.18
15. Vertigo	.21	.67*	.23	.24
3. Drowsiness	.28	.61*	.32	.27
11. Fullness of head	.18	.60*	.38	.32
23. Difficulty equilibrating	.33	.46*	.26	.23
5. Eye strain	.13	.35	.74*	.11
4. Headache	.14	.12	.73*	.16
12. Blurred vision	.22	.22	.67*	.03
2. Fatigue	.36	.27	.57*	.22
6. Difficulty focusing	.26	.50*	.50*	.28
16. Visual flashbacks	.28	.36	.46*	.42*
24. Muscle stiffness from strain	.16	.10	.24	.74*
22. Pallor	.33	.28	-.09	.70*
19. Confusion	.32	.29	.09	.69*
10. Diff. concentrating	.16	.22	.34	.63*
1. General discomfort	.35	.35	.47*	.47*

3.3 RSSQ Scoring Procedure

This section describes development of the scoring system for the RSSQ that incorporates the weighted symptom values chosen by the specialists. Table 5 shows the symbols used in this scoring procedure. Figure 4 shows the scoring procedure steps. The RSSQ's total severity scores and subscale scores for each subject are calculated in steps 1-6. The purpose of steps 7-9 is to transform the RSSQ total severity and subscale scores to have equal variance, following the procedure used by Kennedy et al. (1993).

Table 5. Symbols Used in Scoring Procedure

S_i	Number of symptoms in RSSQ i = 1, 2, …. , n, n = 24
F_j	Number of factors (symptom types) obtained by factor analysis j = 1,2,…m, m = 4
L_{ij}	Varimax loading value obtained from factor analysis
w_i	Weights of each symptom chosen by a group of specialists $\sum_i w_i = 1$
d_i	The difference between the RSSQ scores for symptom i (11-point scale) from before and after the subject's simulator exposure.
h	The Varimax loading reference value of each symptom in factor (h = 0.4)
SD_j	Standard deviation of $\sum_i w_i d_i$ for all subjects on factor j
SD_t	Standard deviation of $\sum_j \sum_i w_i d_i$ for all subjects across all factors
SD_T	Average of every SD_j and SD_t
C_j	Standardized coefficient for each symptom type $C_j = SD_T / SD_j$
C_T	Standardized coefficient for total score $C_T = SD_T / SD_t$

3.3.1 Scoring Procedure Steps for RSSQ

Step 1: Construct table for the Varimax loadings for each factor.

	F_1	F_2	…….	F_m
S_1	L_{11}	L_{12}	…….	L_{1m}
S_2	L_{21}	L_{22}	…….	L_{2m}
.	.	.	.	.
.	.	.	.	.
.	.	.	…….	.
S_n	L_{n1}	L_{n2}		L_{nm}

Step 2: Compare each Varimax loading value (L_{ij}) to the reference value (h) and if L_{ij} is greater than or equal to h , then L_{ij} is replaced with the weighted value of a factor (w_i) and skip to Step 4. Otherwise, proceed to Step 3.

Step 3: If L_{ij} is less than h , replace L_{ij} with w_i = 0.

Step 4: If all L_{ij} values are replaced, proceed to Step 5. Otherwise go back to Step 2.

Step 5: For symptom i of a subject's RSSQ, w_i is multiplied by d_i . Make a new table with these values. Take the sum of each j column and add the sums together to get the total sum.

Step 6: If this new table is completed for every subject, proceed to Step 7. Otherwise, return to Step 5.

Step 7: Take the standard deviation (SD_j) for the sum of each symptom type's $w_i d_i$ value for all subjects. Next, calculate the standard deviation (SD_t) of all $\sum_j \sum_i w_i d_i$ values and calculate SD_T accordingly.

Step 8: Calculate the standardized coefficient C_j by using SD_j and SD_T from above and calculate the standardized coefficient C_T.

$$C_j = SD_T / SD_j$$
$$C_T = SD_T / SD_t$$

Step 9: Calculate each subscale and total score by multiplying $\sum w_i d_i$ by C_j and, multiply $\sum_j \sum_i w_i d_i$ by C_T.

Table 6. Weighted Values for Symptoms in Factors from Specialists

	Weighted Values for Sub-symptoms based on Specialists			
SYMPTOMS (Before / After RSSQ)	N Nausea	D Disorientation	O Ocular Discomfort	C Strain/ Confusion
1. General discomfort			0.00932	0.00932
2. Fatigue			0.01244	
3. Drowsiness		0.00450		
4. Headache			0.04137	
5. Eye-strain			0.04594	
6. Difficulty focusing		0.04297	0.04297	
7. Increased salivation	0.00602			
8. Sweating	0.01435			0.01435
9. Nausea	0.09195			
10. Diff. concentrating				0.03391
11. Fullness of head		0.02909		
12. Blurred vision			0.03132	
13. Dizzy (EO)		0.06847		
14. Dizzy (EC)		0.05927		
15. Vertigo		0.08426		
16. Visual flashbacks			0.03412	0.03412
17. Awareness of breathing	0.03130			
18. Stomach awareness	0.03228			
19. Confusion				0.01765
20. Burping	0.00622			
21. Vomiting	0.17786			
22. Pallor				0.03572
23. Difficulty equilibrating		0.005716		
24. Muscle stiffness for strain				0.03252
Total	[1]	[2]	[3]	[4]
Score N=[1]×31.23 D=[2]×33.59 O=[3] ×61.12 C=[4] ×92.85 TS=([1]+[2]+[3]+[4]) ×12.86 Blank is zero				

3.3.2 Numerical example

This section illustrates calculation of RSSQ scores using the weightings presented in Table 6. As an example, one subject's responses before and after VR exposure are presented in Table 7. The subject's ratings used the 11-point scale described previously.

Table 7. Subject's responses an example

Symptoms	Before VR	After VR	Difference(d_i)
1. General discomfort	1	4	3
2. Fatigue	0	2	2
3. Drowsiness	0	1	1
4. Headache	2	3	1
5. Eye-strain	0	2	2
6. Difficulty focusing	0	0	0
7. Increased salivation	2	0	-2
8. Sweating	1	0	-1
9. Nausea	0	0	0
10. Diff. concentrating	0	1	1
11. Fullness of head	0	1	1
12. Blurred vision	0	2	2
13. Dizzy (EO)	1	2	1
14. Dizzy (EC)	2	2	0
15. Vertigo	0	4	4
16. Visual flashbacks	0	3	3
17. Awareness of breathing	0	1	1
18. Stomach awareness	1	1	0
19. Confusion	0	0	0
20. Burping	0	0	0
21. Vomiting	0	0	0
22. Pallor	0	1	1
23. Difficulty equilibrating	1	1	0
24. Muscle stiffness for strain	0	1	1

Find each factor's $\sum_i w_i d_i$

[1] Total of Nausea = $\sum_i w_i d_i$

= (0×3)+(0×2)+(0×1)+(0×1)+(0×2)+(0×0)+(0.00602×-2)+(0.01435×1)
+(0.09195×0)+(0×1)+(0×1)+(0×2)+(0×1)+(0×0)+(0×4)+(0×3)+(0.03130×1)
+(0.03228×0)+(0×0)+(0.00622×0)+(0.17786×0)+(0×1)+(0×0)+(0×1)
= 0.04910

[2] Total of Disorientation = $\sum_i w_i d_i$ = 0.4391

[3] Total of Ocular Discomfort = $\sum_i w_i d_i$ = 0.35109

[4] Total of Strain/Confusion = $\sum_i w_i d_i$ = 0.21812

Calculate each subscale by multiplying $\sum w_i d_i$ with standardized coefficient C_j

Nausea = [1] × 31.23 = 0.154
Disorientation = [2] × 33.59 = 14.75
Ocular Discomfort = [3] × 61.12 = 21.46
Strain/Confusion = [4] × 92.85 = 20.25

Calculate Total score by multiplying $\sum_j \sum_i w_i d_i$ by standardized coefficient C_T

Total score = ([1] + [2] + [3] + [4]) ×12.86 = 13.03

4.0. COMPARISON OF RSSQ AND SSQ

In the previous sections a new simulator sickness questionnaire, the RSSQ, is described. RSSQ and SSQ scores were calculated from data that were collected during a driving simulator study using 64 subjects (Section 3.1). The original data were collected using the 11-point RSSQ scale. Data for the 16 symptoms used on the SSQ were obtained by transforming the 11-point RSSQ scale for those symptoms to the 4-point SSQ scale as follows: RSSQ 0-1 = SSQ 0; RSSQ 2-4 = SSQ 1; RSSQ 5-7 = SSQ 2; RSSQ 8-10 = SSQ 3

Table 8 shows the percentile scores for RSSQ and SSQ scores and their respective descriptive statistics based on the data collected from the 128 questionnaires. The RSSQ averages and standard deviations are different from those of the SSQ because the theoretical upper and lower limits of the questionnaires differ drastically.

Table 8. Percentiles and Descriptive Statistics for RSSQ and SSQ Score in Driving Simulator Study

PERCENTILE	RSSQ Scores					SSQ Scores			
	D	O	N	C	TS	N	O	D	TS
10	-1.64	-2.89	-2.35	-.65	-1.55	0	0	0	0
20	0	0	-.64	0	0	0	0	0	0
30	.76	1.83	0	1.77	1.58	0	7.58	0	7.48
40	3.18	3.23	.91	3.87	3.22	9.54	7.58	13.92	11.22
45	3.55	4.31	1.3	5.2	3.99	9.54	15.16	13.92	14.96
50	5.11	6.12	1.61	6.41	5.74	9.54	15.16	13.92	22.44
55	7.57	7.62	2.62	8.22	6.47	9.54	22.74	27.84	26.18
60	8.36	8.75	3.43	9.67	7.47	19.08	30.32	41.76	33.66
65	9.86	9.75	5.17	11.17	9	19.08	37.9	41.76	41.14
70	11.14	13.61	6.26	13.63	11.53	28.62	45.48	55.68	48.62
75	14.64	16.68	11.06	16.36	14.03	38.16	53.06	69.6	56.1
80	16.26	20.42	13.79	18.61	20.83	47.7	60.64	83.52	63.58
85	21.08	26.01	17.34	23.85	24.83	57.24	68.22	111.36	78.54
90	27.12	34.6	24.46	29.72	29.64	76.32	83.38	139.2	100.98
95	46.6	42.7	42.33	45.14	44.85	95.4	98.54	180.96	138.38
100	78.95	63.2	75.75	82.75	82.02	152.64	128.86	250.56	183.26
M	10.54	11.03	8.1	11.52	10.75	26	31.17	47.54	38.35
SD	15.65	15.67	15.68	15.68	15.63	34.6	34.08	61.52	44.04
Min*	-16.49	-18.39	-11.18	-10.43	-8.44	0	0	0	0
Max*	78.95	63.2	75.75	82.75	82.02	152.64	128.86	250.56	183.26
Upper limit**	108.9	119.1	100.9	154.2	121.8	200.34	159.18	292.32	235.62
Lower limit**	-108.9	-111.91	-100.9	-154.2	-121.8	0	0	0	0

* Min / max values are from experiment data

** Upper limit / lower limit are theoretical values

Table 9 shows the correlation coefficients for subscale scores and total score from both questionnaires. All the correlation coefficients are 0.7 or greater; therefore, the scores for the RSSQ and SSQ are closely related.

Table 9 Correlation coefficients for subscale scores and total score from RSSQ and SSQ.

	TS	D	O	N	C
Correlation Coefficient	.8295	.8135	.7343	.8082	-

5.0 DISCUSSION

5.1. Advantages of RSSQ

Derived from the SSQ, a new RSSQ with four subscales and an overall total score was developed. We suggest 5 advantages of the RSSQ relative to the SSQ:

- the RSSQ includes 8 more symptoms than the SSQ;
- the RSSQ includes weights to capture the relative importance of each symptom;
- the RSSQ is based on data derived from normal-population subjects rather than a special class of people;
- the RSSQ scoring system considers the subject's baseline physiological condition which permits comparison of pre- versus post-VR exposure;
- the RSSQ's fourth subscale, the strain/confusion factor, has 7 symptoms for strain or confusion. We suggest that this factor could reveal aspects of SS related to initial exposure to a simulator.

The SS that general-population subjects experienced was usually nothing or minimal because the driving simulation we used was only mildly provocative. Since this is the case for the majority of the subjects, the large group variability resulted from those few who did get sick. Weighting their responses by the ratings from the specialists reduced the impact of the few subjects who did get sick.

5.2 Contributions of the RSSQ

A major contribution of the new RSSQ procedure is that it permits evaluation of a new component of SS, which we label strain / confusion. This new component may be related to the new symptoms included in the RSSQ but not the SSQ. In addition, the RSSQ scores are based on changes in symptoms after simulator exposure relative to symptom levels prior to exposure. In other words, the RSSQ readily permits evaluation of subjects' baseline status.

A second major contribution of the present study is validation of the SSQ with a vastly different population (civilian Koreans) using a simulation that was only mildly provocative.

5.3 Application of RSSQ

The results of this research can be used in many ways. The total score (total severity) indicates the general severity of sickness. It also provides the best assessment of the potential for a simulator to cause sickness. Furthermore, the scores of individual symptoms can provide diagnostic information on certain characteristics of sickness. A common issue today relates to simulator sickness in VR devices. The RSSQ can be applied not only to vehicle simulators but also to VR situations as has been done in several recent studies at the Human Interface Technology Laboratory (Lin, Abi-Rached, Furness & Parker, 2002; Lin, Abi-Rached, Kim, Furness, Parker, 2002; Lin, Duh, Abi-Rached, Parker, Furness, 2002). As noted previously, relative ease of comparing repeated exposures to a VR system using the RSSQ may be useful for the within-subjects experimental designs that are commonly used in VR research.

5.4 Future research

The Kennedy et al. (1993) SSQ scores were obtained from 1,119 subjects, which makes it highly credible. The RSSQ used only 1 simulator and data from 64 subjects to develop the scale. Therefore, research that uses more subjects and a variety of simulators will be needed to increase the reliability of the RSSQ.

The values of the 128 RSSQ questionnaires were obtained from subjective reports. Research to obtain more objective scores, possibly using physiological responses, might be pursued in future studies.

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