A study of detecting and combating cybersickness with fuzzy control for the elderly within 3D virtual stores

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Abstract

Elderly individuals can access online 3D virtual stores from their homes to make purchases. However, most virtual environments (VEs) often elicit physical responses to certain types of movements in the VEs. Some users exhibit symptoms that parallel those of classical motion sickness, called cybersickness, both during and after the VE experience. This study investigated the factors that contribute to cybersickness among the elderly when immersed in a 3D virtual store. The results of the first experiment show that the simulator sickness questionnaire (SSQ) scores increased significantly by the reasons of navigational rotating speed and duration of exposure. Based on these results, a warning system with fuzzy control for combating cybersickness was developed. The results of the second and third experiments show that the proposed system can efficiently determine the level of cybersickness based on the fuzzy sets analysis of operating signals from scene rotating speed and exposure duration, and subsequently combat cybersickness.

1. Introduction

1.1. General introduction

Internet stores have received a considerable amount of attention from researchers and practitioners as one of the most promising applications for customers’ online purchases. These stores enable customers to buy what they want at their convenience. These stores also allow users to imagine themselves buying, owning, and enjoying their purchases (Davis, 2001). In our modern culture, people’s self-identification is related to what they purchase and how they use these purchases. Online shopping has been popular ever since its introduction.

Although a smaller percentage of older adults (i.e., the silver tsunami) use the web than younger individuals, surveys indicate a possible change in this trend. The World Health Organization estimates that by 2020, 24% of Europeans, 17% of Asians, and 23% of North Americans will be over 60 (World Health Organization report, 1997). By 2020, more than 1 billion people will be at least 60 years old worldwide. The inception of an elderly society will highlight problems that many older adults have with performing daily tasks because of restricted mobility, lack of transportation, inconvenience, and fear of crime (Czaja and Lee, 2003). Home computers with an internet connection can provide this population with a new channel for accessing information and services (Jones, 2009). However, traditional web shops only display commodities using two-dimensional (2D) pictures and a catalog description, which is not realistic and cannot capture the users’ interaction with goods (Ding et al., 2005). These types of problems can now be solved using a virtual environment (VE: a desktop virtual reality (VR)). A VE is a computer-generated, 3D representation of a setting within which the users of the technology perceive themselves and interact. A VE is sometimes also called a virtual landscape, virtual space, or virtual world.

1.2. Cybersickness in VEs

Contemporary VEs do not exactly match real world environments because of technological limitations. This contributes to some users experiencing symptoms similar to those of classical motion sickness both during and after a VE experience (Rich and Braun, 1996). This type of sickness, called cybersickness, is believed to occur primarily because of conflicts among three sensory systems: visual, vestibular, and proprioceptive, during use of VR equipment (e.g., the heaviness of the helmet used and the proximity of the screen to the user’s eyes) (Stanney et al., 2002). Some studies have reported that the sickness differs from motion sickness because the stationary user has a compelling sense of motion that is induced through exposure to changing visual imagery (Stanney, 2002; Lathan, 2001). Factors such as user experience, gender, age, illness, flicker fusion frequency threshold,
ment of rotation ability, and susceptibility to vection have related to the susceptibility to sickness in different ways. Most results have shown that the conflict produced by visual interaction is the major cause of cybersickness. Dichgans and Brandt (1972) reported a convergence of visual and vestibular information, which suggests that watching moving scenes will directly stimulate the vestibular neurons and cause vection sensation when the sensory information is not the stimulus that the subject expected based on his/her prior experience. 

So et al. (2001) found that vection and sickness can be generated by the stimulus that the subject expected based on his/her prior experience. Therefore, the effects of virtual scene rotation and the rotating speed on sickness should be considered when immersing the elderly in a 3D virtual store. Kennedy et al. (2000) found that a variance between 20% and 50% is a conservative estimate for the incidence and severity of cybersickness. These authors found that the exposure duration and repeated exposures were significantly linearly related to the sickness outcomes. To date, a directly predictive VE sickness model for the elderly has not been produced because the considered factors do not account for the variance in the sickness outcome as well as the temporal duration factor. The goal of this study was to propose an efficient method for reducing cybersickness in the elderly.

1.3. Objectives

High-quality 3D images improve the realism and presence of VEs but can also exacerbate sickness. Cybersickness is a problem that must be corrected to make VEs usable by the elderly, because 3D virtual stores will be a popular shopping style for the elderly. Thus, the salient question is how to eliminate cybersickness or sufficiently reduce its severity such that the elderly who are susceptible to cybersickness can use VEs. The purpose of this study is to investigate the effects of virtual scene rotation and exposure duration on the elderly during exposure to a 3D virtual store in order to be able to use the primary factors that contribute to cybersickness to design a warning system with fuzzy control to reduce cybersickness.

2. Experiment I

2.1. Participants, apparatus, and the virtual store

Thirty-two elderly people (13 females and 19 males between the ages of 65 and 71, with an average age of 66.5 years) participated in the experiment. All of the participants were required to undergo an eye test and color vision test. During the eye test, the Snellen eye chart developed by the Dutch eye doctor Hermann Snellen in the 1860s was used to measure a participant’s distance vision. The eye chart was located on a wall that was 20 feet away from a participant’s eyes. 20/20 vision (or more accurately, 20/20 visual acuity) means that an individual can read a letter that is 20 feet away. An assistant asked the participants to identify the line with the smallest text letters that they could discern and to read this line. If the participants could read the bottom row of letters, their visual acuity was considered to be extremely good. The International Classification of Visual Performance (which was used by WHO in the International Classification of Diseases (ICD-9) and recommended by the International Council of Ophthalmology in Kyoto (1978)) states that normal vision is 20/25 to 20/12 (Visual Functions Committee, 1988). The color vision test was used to determine a participant’s ability to distinguish different colors. Four cards with colored dot patterns were used for testing purposes. Some of the dots appeared to form numbers or symbols in the patterns. Participants were asked to identify the numbers or symbols that they were able to discern. After completing the tests, all of the participants had normal vision or corrected-to-normal vision (i.e., the participants scored between .83 and 1.11 in the eye test) and normal color vision. The Human Development Index (HDI) of the samples was .89 in 2012 (i.e., the life expectancy at birth was 79.5 years; the tertiary education gross enrollment rate was 83.4%; the GDP per capita was USD 20,386) (DGBAS Social Indicators in Taiwan, 2013). The HDI is a composite statistic that is used as an index to rank countries by their level of “human development” and to separate developed countries (i.e., those with a high level of development), developing countries (i.e., those with a medium level of development), and underdeveloped countries (i.e., those with a low level of development) from each other. A HDI of .8 or more is considered to represent “high development”. Therefore, the samples were classified as a “high development” group. The experimental environment was constructed using virtual software and presented on a 22 in. thin-film transistor liquid crystal display (TFT-LCD). The designed scene was a retail store for automobile peripheral fittings for portable devices (see Fig. 1).

2.2. Study hypothesis and objective

The following hypothesis was proposed:

Faster rotations of the visual scene and longer exposures within a virtual store result in higher levels of cybersickness.

This hypothesis was based on the assumption that rapid rotations over a prolonged period of exposure cause a mismatch between

![Fig. 1. The 3D simulated retail store (left) and products showed on the shelf (right).]
sensation and vestibular cues. Lo and So (2001) found that scene oscillations produced vection and induced cybersickness. Kennedy et al. (2000) reported that the duration was positively related to simulator sickness. Based on these results, the vection during rapid rotations over a prolonged exposure period was assumed to be associated with a sensory mismatch. We conducted an experiment with passive tasks, constructed to verify this hypothesis.

2.3. Questionnaires

We used a Simulator Sickness Questionnaire (SSQ) originally devised to evaluate computer-based simulator systems. It consists of a checklist of 16 sickness symptoms on three subscales that represented separable but somewhat correlated dimensions of simulator sickness, oculomotor, nausea, and disorientation. The SSQ score is computed by adding together the ratings of all of the symptoms and multiplying this value by an appropriate weight. The weights are 7.58 for oculomotor, 9.54 for nausea, and 13.92 for disorientation. The total cybersickness severity is computed by adding the sums of the oculomotor, nausea, and disorientation symptom ratings and multiplying the resulting value by 3.7 (Kennedy and Lane, 1993). Kennedy and Lane (1993) found that nausea symptoms seldom occurred for an SSQ score below 7.5. When the score was between 7.5 and 22.5, at least one nausea symptom occurred. When the score was above 22.5, the symptoms of nausea increased quickly. Lo and So (2001) reported that the mean post-exposure SSQ score was 35 in a VR experiment involving scene oscillation: over 50 percent of the participants that were exposed for 20 min reported an increase in general discomfort, eyestrain, fullness of head, fatigue, and difficulty in focusing. Stoffregen et al. (2000) studied sickness induced by a fixed-base flight simulator for a 2-h exposure time: the mean post-exposure SSQ score was 34.75, and some participants experienced heavy rapid breathing, uneasiness, drowsiness, and eyestrain. Kiryu et al. (2008) reported that shaky video images caused visually induced cybersickness. After the subjects viewed an 18-min-long video, the total severity score of the SSQ was 27.9 ± 9.1, and the major component was nausea. The SSQ is valid, reliable, and the most popular subjective measure for both simulator sickness and the side effects experienced in VEs (Kiryu and So, 2007; Hale and Stanney, 2006). Therefore, the SSQ was used to measure subjective symptoms of cybersickness in this study.

2.4. Experimental design and procedures

In our first experiment, three factors (i.e. the scene rotating speed, scene inclination angle, and duration of exposure) were measured to evaluate the primary effects on cybersickness. Therefore, a randomized block design with \(4 \times 4\) Latin squares was used. In general, a Latin square design is based on experimental units with row-and-column block structures. In this study, we blocked the scene rotating speed (the row) and scene inclination angle (the column). Then, treatments were defined in terms of the four levels of exposure duration. Each treatment appeared once in every row and once in every column. Each participant was randomly assigned one of the 16 conditions. That is, each condition was assigned to two participants. VE users generally experience more rotation around a vertical axis than around lateral and fore-and-aft axes. Reid et al. (1994) reported that the vection generated during exposure to a scene rotating around a vertical axis caused symptoms of nausea in over half of the participants. It means that the elderly may be sensitive to the scene rotating speed. Therefore, the study was designed with four scene rotating speeds around a vertical axis of 15, 30, 45, and 60°/s and four levels of scene inclination with respect to a lateral axis (clockwise) of 0, 15, 30, and 45. So et al. (2001) found that the mean vection and nausea ratings increased significantly after 5 and 10 min, respectively, of navigation of a virtual city. Similarly, Regan (1995) reported that subjects experienced progressively more symptoms of sickness over an exposure of 20 min in a VE. Thus, for our experimental design exposure durations of 5, 10, 15, and 20 min were chosen.

All of the participants were exposed to the same VE. The VE was controlled by a program during exposure. First, the scene was rotated for one complete circle at the door gate along the vertical axis with a set rotating speed and angle. The scene was then moved forward along the fore-and-aft axis for 5 s at .2 units of translate vector per second before being rotated for one complete circle. Next, the scene was turned to the right and moved forward to the end of the showroom. The scene was then moved back to the door gate and rotated for one complete circle. The scene was then turned left and moved forward to the end of the showroom. Finally, the scene was returned to the door opening. The scene was halted for 5 s at each step. This cycle was repeated until the experimental time had elapsed. During the exposure period, the participants were required to search for six target objects (see Table 1). To ensure the participants’ attention to this task, some of the objects on the check sheet did not appear in the VE. Only four of the objects were displayed in the showroom, but the participants were not made aware of this action. There were 2 assistants observing the behavior of the participants during the experiments. They found that the participants spent more time looking at objects that were not in the showroom than on those that were. Some participants continually asked for the objects that were not in the showroom. Therefore, 2 products left out of the showroom would keep the participants engaged in the experiment.

2.5. Results

Sickness measures (i.e., the scores on the SSQ) were obtained from the participants before and after VE exposure (see Table 2). The difference between the pre- and post-exposure total sickness severity scores was used in the analysis. A significant difference was found between the scores before and after the VE exposures (\(r(31)=12.705, p=.000\)), indicating that the post-exposure symptoms of cybersickness were more prevalent than the pre-exposure symptoms. The post-exposure SSQ scores for 16 symptoms indicated that over 50 percent of the subjects reported an increase in fatigue, eyestrain, difficulty with focusing, and difficulty with concentrating.

<table>
<thead>
<tr>
<th>No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objects</td>
<td><img src="image1.png" alt="Object 1" /></td>
<td><img src="image2.png" alt="Object 2" /></td>
<td><img src="image3.png" alt="Object 3" /></td>
<td><img src="image4.png" alt="Object 4" /></td>
<td><img src="image5.png" alt="Object 5" /></td>
<td><img src="image6.png" alt="Object 6" /></td>
</tr>
<tr>
<td>Showing in the showroom or not?</td>
<td><img src="image7.png" alt="Yes" /></td>
<td><img src="image8.png" alt="No" /></td>
<td><img src="image7.png" alt="Yes" /></td>
<td><img src="image8.png" alt="No" /></td>
<td><img src="image7.png" alt="Yes" /></td>
<td><img src="image8.png" alt="No" /></td>
</tr>
</tbody>
</table>

Table 1
Sheet of target objects in the first experiment.
increased more slowly at 30 and 45
participants was low within 5 min of exposure, increased signi
cincidence and severity of cybersickness experienced by the parti-
crease of SSQ symptoms signi
results partially supported the second hypothesis: the rate of
Thus, rotating the scene around a vertical axis in a virtual store
exposure time gradually enables them to adapt to a VE. This
and Sharkey (1992) reported that allowing users to increase their
After VE exposure SSQ scores for viewing the virtual store with moving
output variable, the sickness rating. The two input variables were
Table 3 presents the ANOVA results associated with the post-
crease SSQ scores for viewing the virtual store with moving
Scene rotating speed 252.752 3 84.251 6.212 .003*
Scene inclination 57.168 3 19.056 1.405 .268
Exposure duration 3366.171 3 1122.057 82.729 .000*
Error 298.394 22 13.563
Total 3974.485 31
* Indicates significant difference at p < .05.

Table 3
ANOVA of the post-exposure SSQ scores for the effects of viewing a virtual store with moving scenes on a non-immersive stereoscopic display.

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scene rotating speed</td>
<td>252.752</td>
<td>3</td>
<td>84.251</td>
<td>6.212</td>
<td>.003*</td>
</tr>
<tr>
<td>Scene inclination</td>
<td>57.168</td>
<td>3</td>
<td>19.056</td>
<td>1.405</td>
<td>.268</td>
</tr>
<tr>
<td>Exposure duration</td>
<td>3366.171</td>
<td>3</td>
<td>1122.057</td>
<td>82.729</td>
<td>.000*</td>
</tr>
<tr>
<td>Error</td>
<td>298.394</td>
<td>22</td>
<td>13.563</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3974.485</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates total scores in SSQ.

considered fuzzy sets. One input variable was the fuzzy set \( \tilde{S} \), which represented the “Scene rotating speed” around a vertical axis. This set was described by three attributes: a “slow speed” (SS) (i.e., \( \mu_{SS}(x) \)), “medium speed” (MS) (i.e., \( \mu_{MS}(x) \)), and “quick speed” (QS) (i.e., \( \mu_{QS}(x) \)). The second set was the fuzzy set \( \tilde{D} \), which was the “Exposure duration”. This set was described by three attributes: a “short exposure duration” (SD) (i.e., \( \mu_{SD}(y) \)), “medium exposure duration” (MD) (i.e., \( \mu_{MD}(y) \)), and “long exposure duration” (LD) (i.e., \( \mu_{LD}(y) \)). Here, \( \mu_{SS}(x) \) and \( \mu_{SD}(y) \) are L-shaped membership functions that are defined as follows:

\[
\mu_{SS}(x) = \begin{cases} 
1 & \text{if } x < a_{11}, \\
\frac{a_{12} - x}{a_{21} - a_{11}} & \text{if } a_{11} \leq x \leq a_{12}, \\
0 & \text{if } x > a_{12},
\end{cases}
\]

(1)

where \( a_{11} \) and \( a_{12} \) are the parameters of the membership function \( \mu_{SS}(x) \). The membership function \( \mu_{SD}(y) \) is similar to \( \mu_{SS}(x) \) and is defined by two parameters, \( b_{11} \) and \( b_{12} \). The functions \( \mu_{SS}(x) \) and \( \mu_{SD}(y) \) are triangular-shaped membership functions that are defined as follows:

\[
\mu_{SD}(x) = \begin{cases} 
0 & \text{if } a_{21} \leq x \leq a_{22}, \\
\frac{x - a_{21}}{a_{22} - a_{21}} & \text{if } a_{22} < x \leq a_{23}, \\
0 & \text{otherwise}.
\end{cases}
\]

(2)

where \( a_{21} \), \( a_{22} \), and \( a_{23} \) are the parameters of the membership function \( \mu_{SD}(x) \) and the value of \( a_{22} \) is equal to \( a_{12} \). The membership function \( \mu_{SD}(y) \) is similar to \( \mu_{SS}(x) \) and is defined by parameters \( b_{11} \) and \( b_{12} \). Kennedy and Lane (1993) demonstrated that nausea symptoms seldom occur for a SSQ score below 7.5. When the SSQ score was between 7.5 and 22.5, at least one nausea symptom occurred. When the SSQ score was above 22.5, the nausea symptoms increased rapidly. Therefore, an SSQ score of 15 (i.e., 22.5 plus 7.5) was used for the initial value of the parameter \( a_{11} \) for \( \tilde{S} \). A score of 22.5 was used for the initial value of the parameter \( a_{22} \), and a score of 30 (i.e., 22.5 plus 7.5) was used for the initial value of the parameter \( a_{32} \). How should these parameter values be assigned? The results from the previous experiment indicated that the mean SSQ scores for rotating speeds of 15, 30, 45, and 60/s were 20.27, 23.28, 27.19, and 31.62, respectively. Using a linear interpolation corresponding to an SSQ score of 15, the crisp value of \( a_{11} \) was estimated to be approximately .01/s. Similarly, the crisp value of \( a_{22} \) for an SSQ score of 22.5 was 27.0/s, and the crisp value of \( a_{32} \) for an SSQ score of 30 was 54.5/s (see Fig. 2). The experimental results also indicated that the mean SSQ scores for exposure durations of 5, 10, 15, and 20 min were 10.53, 23.67, 29.36, and 32.14, respectively. Similarly, the crisp values of \( b_{11} \), \( b_{22} \), and \( b_{32} \) were estimated to be approximately 6.70, 9.55, and 16.15 min, respectively (see Fig. 3).

The output variable for sickness prediction, the fuzzy set \( \tilde{R} \), was defined in terms of “sickness ratings” that included the following attributes: “No symptoms” (NO), “Slight” (ST), “Mild” (MD), “Moderate” (MO), and “Serious” (SE). Five membership functions (\( \mu_{NO} \), \( \mu_{ST} \), \( \mu_{MO} \), \( \mu_{MD} \), \( \mu_{SE} \)) were defined over the continuous domain \([0, 100]\). According to the study of Kennedy and Lane (1993), when the SSQ score is smaller than 7.5, the symptom of nausea seldom occurs. When the score is between 7.5 and 22.5, at
least one symptom of nausea will occur. When the score is larger than 22.5, the symptoms of nausea increase rapidly. We assigned 7.5, 15, 22.5, 30, 37.5 to the crisp center values of membership functions of the output fuzzy set. Fig. 4 illustrates the shape of the membership functions of the output fuzzy set. Finally, IF-THEN rules were defined to enable fuzzy reasoning. The i-th rule had the following form:

\[ \text{Rule } i: \text{ IF } x \in S(i) \text{ AND } y \in D(i) \text{ THEN } r \in R(i), \]

(4)

where \( S(i), D(i), \) and \( R(i) \) are the linguistic values taken by \( x, y, \) and \( r \), respectively, in the i-th rule. There were 9 rules in the fuzzy logic reasoning system, as shown in Table 6. The processing stage is shown in Fig. 5.

The fuzzy warning system was designed as a module program written in the VE platform. The system used programs to input the data of the scene rotating speed and exposure duration to the two fuzzy sets: \( \mathcal{S} \) (the Scene rotating speed) and \( \mathcal{D} \) (the Exposure duration) when the 3D virtual store was running. The system was

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**Table 4**

Scheffe's post hoc tests for the effects of duration on SSQ scores of post-exposure.

<table>
<thead>
<tr>
<th>(I) Duration (min)</th>
<th>(J) Duration (min)</th>
<th>Mean difference (I-J)</th>
<th>Standard errors</th>
<th>Sig.</th>
<th>95% Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>17.8275*</td>
<td>1.70118</td>
<td>.000</td>
<td>-23.1303</td>
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<td>15</td>
<td>20</td>
<td>26.1800*</td>
<td>1.70118</td>
<td>.000</td>
<td>-31.4828</td>
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<td>5</td>
<td>17.8275*</td>
<td>1.70118</td>
<td>.000</td>
<td>12.5247</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>-6.0150</td>
<td>1.70118</td>
<td>.023</td>
<td>11.3178</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>8.3525*</td>
<td>1.70118</td>
<td>.002</td>
<td>3.0497</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>2.3375</td>
<td>1.70118</td>
<td>.607</td>
<td>7.0653</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>-2.3375</td>
<td>1.70118</td>
<td>.607</td>
<td>-7.6403</td>
</tr>
</tbody>
</table>

* Indicates significant difference at \( p < .05 \).

**Table 5**

Scheffe’s post hoc tests for the effects of scene rotating speed on SSQ scores of post-exposure.

<table>
<thead>
<tr>
<th>(I) Scene rotating speed</th>
<th>(J) Scene rotating speed</th>
<th>Mean difference (I-J)</th>
<th>Standard errors</th>
<th>Sig.</th>
<th>95% Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>15/s</td>
<td>30/s</td>
<td>3.2100</td>
<td>1.70118</td>
<td>.346</td>
<td>-8.5128</td>
</tr>
<tr>
<td>45/s</td>
<td>30/s</td>
<td>4.1450</td>
<td>1.70118</td>
<td>.358</td>
<td>-9.4478</td>
</tr>
<tr>
<td>30/s</td>
<td>45/s</td>
<td>7.8550*</td>
<td>1.70118</td>
<td>.003</td>
<td>-13.3878</td>
</tr>
<tr>
<td>60/s</td>
<td>30/s</td>
<td>4.1500</td>
<td>1.70118</td>
<td>.358</td>
<td>-9.4478</td>
</tr>
<tr>
<td>45/s</td>
<td>60/s</td>
<td>7.8550*</td>
<td>1.70118</td>
<td>.003</td>
<td>-13.3878</td>
</tr>
<tr>
<td>60/s</td>
<td>45/s</td>
<td>7.8550*</td>
<td>1.70118</td>
<td>.003</td>
<td>-13.3878</td>
</tr>
<tr>
<td>45/s</td>
<td>30/s</td>
<td>7.8550*</td>
<td>1.70118</td>
<td>.003</td>
<td>-13.3878</td>
</tr>
</tbody>
</table>

* Indicates significant difference at \( p < .05 \).

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**Fig. 2.** Membership function of fuzzy set \( \mathcal{S} \).**

**Fig. 3.** Membership function of fuzzy set \( \mathcal{D} \).**

**Fig. 4.** Membership functions of the output fuzzy set “ratings of sickness.”

<table>
<thead>
<tr>
<th>Ratings of cybersickness</th>
<th>Speed of navigation rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow</td>
<td>Medium</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exposure duration</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>No symptom</td>
<td>Slight</td>
<td>Mild</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

**Table 6**

Rule base for cybersickness ratings.
also linked to a voice device. As described in the previous section, sickness rating values of 15, 22.5, and 30 were used in the design of the alarm for combating sickness. When the sickness rating value (variable \( r \)) was higher than 15, the system continuously sounded a 5-s “BEEP”, and the virtual store scene was locked for approximately 1 min. When the \( r \) value was larger than 22.5, the system continuously sounded a 5-s “BEEP”, and the scene was locked for 3 min. When the \( r \) value was higher than 30, the system continuously sounded a 5-s “BEEP”, and the operation was terminated.

4. Experiment II

Two further experiments (i.e. the second and third experiment) were designed to verify the effect of the fuzzy warning system. These experiments had the same experimental environment as the first experiment except that the searching targets were rearranged in the VE (see Table 7). Before the start of the second experiment, two people (aged 67 and 69) were asked to test the fuzzy warning system. These individuals searched for six objects in the virtual store without a time constraint. When they finished this test, they were satisfied with the fuzzy warning system automatically to stop searching as soon as they did not feel well. Each individual required over 30 min to perform the search. Therefore, the effects of the warning system were evaluated for four exposure durations (i.e., 5, 10, 15, and 20 min) in the second experiment.

The same participants were used in the first and second experiments (i.e., thirty-two participants), which were conducted six months apart. The participants may not have clearly remembered the details of the first experiment at the time of the second experiment. Regan and Price (1994) reported that repeated exposure to the same VE within seven days could significantly affect the level of cybersickness. Thus, the effect of cybersickness from our first experiment should be small at the time that our second experiment was conducted. There were two experimental sets: one with and one without the fuzzy warning system. Participants were randomly assigned to one of the sets and then to one of the four exposure durations (i.e., 5, 10, 15, and 20 min). Thus, there were sixteen participants in each of the experiments with and without the fuzzy warning system. During the exposure period, the participants were required to search for six target objects to ensure that the participants were focused on a task. When the target object was found, the participants placed the cursor on the object and pushed the left button on the mouse to identify the object. If the object was the target, the system would beep once to notify the participant. The participant wrote an “O” in the corresponding column at the same time. If the participant determined that a particular target object was not in the showroom, the participant marked an “X” instead. The experimental process was passive in the first experiment and active in the second experiment. That is, in the first experiment, the VE was controlled by a program; in the second experiment, the participants could freely immerse themselves in the VE by manipulating the mouse button and rotating the scene around the vertical or the lateral axes. The participants could also zoom in using the SHIFT key and zoom out using the CTRL key. At the end of the experimental period, the experiment was terminated even if all of the target objects had not been found. The participants were asked to complete the SSQ at the end of the experiment.

When all of the participants finished the second experiment, the differences between the mean scores were analyzed. The
differences between the mean SSQ scores with and without the fuzzy warning system significantly increased at 10 min and continued to increase for 15 to 20 min (see Table 8). These results were consistent with the results from the first experiment, i.e., the SSQ symptoms increased significantly with the exposure duration. In addition the SSQ scores with the fuzzy warning system were not significantly smaller than those without a warning system at 5 min. \( t(6) = -0.3974, p = 0.3524 \) and 10 min. \( t(6) = -0.4173, p = 0.2455 \). The SSQ scores with the fuzzy warning system were significantly smaller than those with ‘no system’ at 15 min. \( t(6) = -3.0000, p = 0.012 \) and 20 min. \( t(6) = -2.2306, p = 0.033 \). Some of the observed differences could be attributed to chance. However, these results confirmed our expectation that the fuzzy warning system reduced sickness in the elderly who were exposed to the virtual store over longer exposure durations more than when the warning system was not used.

5. Experiment III

A different experimental environment (see Fig. 6) and different searching targets (see Table 9) were used in the third experiment than in the second experiment. There were other differences between the second and third experiments. First, the showcases were located in the center of the virtual store in the second experiment but in the area surrounding the store in the third experiment. Second, the experimental time was limited in the second experiment, whereas it was unlimited in the third experiment. A final and important difference between the experiments was that there was an interval of fifteen months between the second and third experiments, and some of the participants were different (15 females and 17 males between the ages of 67 and 73, with an average age of 68.3 years). All of the participants had normal vision or corrected-to-normal vision (i.e., the participants scored between 0.83 and 1.33 on the eye test) and normal color vision. There were two experimental sets, with and without the fuzzy warning system. Each participant was randomly assigned to one of the sets; thus, there were sixteen participants each, in the experiments with and without the fuzzy warning system. In the third experiment, the participants could immerse themselves freely in the VE by manipulating a button on the mouse and rotating the scene around the vertical or lateral axes. The experiment ended when all of the targets were found, i.e., there was no time limit in this experiment. The participants were asked to complete the SSQ at the end of the experiment.

When all of the participants completed the third experiment, the differences between the mean SSQ scores were analyzed. The mean SSQ score of 20.73 that was obtained using the fuzzy warning system was significantly smaller than the mean SSQ score of 25.385 that was obtained without using the system \( t(30) = 2.8820, p = 0.0036 \). This result was consistent with the results from the second experiment, i.e., the fuzzy warning system reduced sickness in the elderly who were exposed to a virtual store over long exposure durations more than when no system was used. However, a longer mean target searching time was found for the set with the fuzzy warning system than for the set with no warning system. With the fuzzy warning system, the system may have locked the scene for a few minutes when the detected “sickness rating” exceeded the threshold value. Therefore, the entire time to complete the task increased. This result also indicated that taking short breaks can alleviate cybersickness symptoms.

6. Discussion

Most studies conducted to date have typically investigated the effect of navigation or exposure duration on the levels of cybersickness in subjects under sixty-five (Sharples et al., 2008; Arns and Cerney, 2005). Some research studies have focused on an immersive VR environment (VRE). A VRE is a promising technology that immerses a user in a virtual world through the use of 3D real-time computer graphics and advanced display devices, such as head mounted displays (HMDs) or Caves (Cruz-Neira et al., 1993). Notably, Kennedy et al. (2010) have reported significant visually induced motion sickness (VIMS) symptoms, as rated by SSQ responses, in only 15 min. Howarth and Clemes (2006) found that symptoms induced by VRE exposure increased in as little as 6 to 10 min. In this study, a 3D virtual store was created using an on-screen small-scale VE, not an immersive VRE. Visitors, which include the elderly, typically browse a VE on a TFT-LCD at offices, home, or elsewhere, not HMDs. The visitor has an egocentric viewpoint within the environment that visually affords the experience of movement, rotation, and changing the elevation of the view in such an environment. Therefore, one of the aims of this experimental study was to investigate the effects that increase the levels of cybersickness in the elderly during and after navigating a VE in a 3D virtual store at different scene rotating speeds and exposure durations. The results of this study indicated that when subjects over sixty-fore viewed a 3D virtual store with moving scenes, the subjects exhibited cybersickness symptoms and that the rate of increase of the SSQ symptoms

![Fig. 6. The 3D simulated retail store in the third experiment.](image)

<table>
<thead>
<tr>
<th>No.</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>Showing in the showroom or not?</td>
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Table 9
Sheet of target objects in the third experiment.
significantly increased with the scene rotating speed and duration of exposure.

The other aim of this study was to utilize the contributing factors to construct a warning system for cybersickness. The results of the first experiment indicated that the scene rotating speed and exposure duration in a VE could be measured, quantitatively analyzed, and then used as predictive variables to estimate the level of cybersickness associated with a particular VE. In this study, fuzzy control technology was used to develop a warning system to combat cybersickness. The results of the second and third experiments demonstrated that the system could efficiently determine the cybersickness states and alert the participant to terminate exposure, thereby reducing cybersickness symptoms. Studies have been conducted on physiological responses to develop an objective measure. Meehan et al. (2005) correlated increased cardiac function with VIMS in VEs, where cardiac activity was a robust measure of performance arousal. Kim et al. (2005) reported that cybersickness accompanied pattern changes in the activities of the central and the autonomic nervous systems. Roberts and Gallimore (2005) successfully constructed cybersickness state estimation models to use shifts in the participants’ electrogastrogram (EGG) data to detect sickness states that were associated with subjective states. However, EGG data are collected using an electrogastrograph. It is difficult to attach special sensors (electrodes) to the stomachs of the elderly to monitor their EGG data and simultaneously predict the levels of cybersickness while they are immersed in a VE. Within a research context, physiological methods may be used to obtain fundamental data to make an objective appraisal of cybersickness: however, measuring physiological responses requires substantial technical expertise on the part of the administrator, which presents a limitation. Attaching electrodes to a client is invasive and time-consuming and requires specialized electrocardiogram (ECG) equipment, thus motivating the development of a less complex assessment tool (Bruck and Watters, 2011). In this study, the fuzzy warning system used the data of the scene rotating speed and exposure duration as inputs to the program to predict the levels of cybersickness. This fuzzy warning system was verified to work well for active tasks and could be easily applied to typical VEs.

In addition, the experimental results confirmed our expectation that a fuzzy warning system would reduce cybersickness levels in the elderly exposed to VE over exposures of long duration more than when the system was not used.

The research described in this paper was set up to consider the efficacy of a method to reduce cybersickness induced by the 3D virtual stores. The data showed that cybersickness can present a significant problem for the elderly during the VE exposure. This study has taken a step in the direction of defining the effects contributing to the increased levels of cybersickness in the elderly during navigating a VE on a TFT-LCD at different navigation rotating speeds and exposure duration. The experiments revealed that the proposed fuzzy control system can efficiently determine the real-time cybersickness status based on the fuzzy sets analysis of operating signals from scene rotating speed and exposure duration. This finding will be useful for research in estimating the severity levels of cybersickness in a particular VE (shown on a non-immersive device: TFT-LCD). The system was also linked to a voice device to produce voice to warn the participant when the judgment index of cybersickness indicates abnormality. The results of experiments showed that the warning system could alleviate cybersickness. The fuzzy warning system could be designed as a module program written in the VE platform. To apply the countermeasure for cybersickness, it will be necessary to study the efficacy of navigation rotating speeds and exposure duration in various 3D virtual environments because different virtual environments may have different critical values in fuzzy sets.

7. Conclusions

In this study, we identified the effects that increase sickness in the elderly in a virtual store for different navigation rotating speeds and exposure durations. The results of this study can help to define the factors that increase cybersickness among the elderly during virtual store visits at different scene rotating speeds and exposure durations. In this study, fuzzy control technology was used to develop a warning system to combat cybersickness based on the results of the first experimental data. The results of the second and third experiments demonstrated that the system efficiently predicted the cybersickness state. In this study, the fuzzy warning system used the rotating speed and exposure duration data as inputs to predict cybersickness levels. This system was verified for active tasks and could easily be applied to similar VEs. In addition, the experimental results confirmed our expectation that the fuzzy warning system could reduce cybersickness in the elderly exposed to a 3D virtual store for long durations more than when the system was not used. This result could be used to reduce cybersickness based on objective estimates of the severity of cybersickness in a particular VE (as shown on a TFT-LCD).

References


