Driving Simulator Sickness: An Evidence-Based Review of the Literature

Sherrilene Classen, Megan Bewernitz, Orit Shechtman

KEY WORDS
- automobile driving
- computer simulation
- motion sickness
- proprioception
- somatosensory disorders

OBJECTIVE. Guided by the Occupational Therapy Practice Framework: Domain and Process (2nd edition; American Occupational Therapy Association, 2008), we conducted an evidence-based review on simulator sickness (SS).

METHOD. We searched Web of Science, PubMed, SafetyLit, Google Scholar, and recently published literature. We used the American Academy of Neurology’s classification criteria to extract data from 10 studies and assign each a level of 1–4, with “1” indicating the highest level of evidence. We grouped studies that addressed SS into client factors, context and environment factors, and activity demands.

RESULTS. Client factors (i.e., older clients (>70 yr; Level B), women [Level B]) and context/environment factors (e.g., refresh rates, scenario design and duration, simulator configuration, and calibration; Level B) probably increase the rates of SS, whereas activity demands (vection, speed of driving, and postural instability; Level C) possibly contribute to SS.

CONCLUSION. We classified factors contributing to SS and identified the need for randomized trials to identify causes of SS.


Driving simulators use computer-based technology to create the impression of driving a vehicle (Stern & Schold Davis, 2006). Simulators vary from desktop configurations using one to three computer monitors to cab configurations with life-sized graphics. They may be fixed base (simulator does not move during the scenarios) or motion based (simulator moves in conjunction with scenario actions). Cost varies on the basis of graphics resolution and motion-based features. For example, high-fidelity simulators with high resolution and fast refresh rates range from $25,000 to >$100,000 (Stern & Schold Davis, 2006).

Occupational therapists use driving simulators to provide a safe alternative to on-road testing: simulated crashes pose little risk to the physical or emotional well-being of users. For example, Stern and Schold Davis (2006) used a simulator in occupational therapy clinical practice to remediate participants’ performance skills (e.g., visually scanning the environment) and patterns (e.g., always checking the right lane before merging). Additional benefits of using a simulator rather than on-road testing to assess driving performance in the research setting include the ability to (1) assess the participant in various controlled driving environments (i.e., variable weather, traffic densities, geographic conditions), (2) tailor situations that are sensitive to people with specific driving impairments (e.g., decreased peripheral vision), (3) test participants under objective and repeatable conditions, and (4) use a smaller space such as a lab or office setting rather than the complex on-road setting. As such, driving simulators have been used to assess driving performance skills, in-vehicle technologies (e.g., lane-departure warning systems), and driver interaction with...
the environment (e.g., negotiating intersections incorporating highway design guidelines; Davidse, 2007; Freund & Colgrove, 2008; Lee, Lee, Cameron, & Li-Tsang, 2003; Shechtman, Classen, Awadzi, & Mann, 2009; Shechtman et al., 2007, 2008).

Despite these benefits, a significant limitation to the widespread use of driving simulators for assessments is the simulator sickness (SS) experienced by a portion of participants during and after a driving simulator session (Shechtman et al., 2007). The factors that cause or contribute to SS are not well known or documented in the occupational therapy literature. This article summarizes determinants of SS (underlying factors associated with or predictive of SS) during driving simulations through an evidence-based literature review. Our hope is that this article will inform occupational therapists about SS symptoms and about its possible contributing factors—a subject that is currently not well understood or well documented in the occupational therapy driving simulator literature.

Simulator Sickness

Simulator sickness can be described as physical discomfort experienced when “driving” a simulated vehicle that is caused by incompatible signals from visual, auditory, and motion systems. SS affects the driver in the absence of true motion and shares many of the same symptoms as motion sickness (Hettinger, Berbaum, Kennedy, Dunlap, & Nolan, 1990). Early signs of SS include pallor, restlessness, and cold sweat and can progress to nausea, excessive salivating and, finally, vomiting. Researchers have attributed many of these symptoms to the function of the autonomic nervous system and increased activation of the sympathetic nervous system (Chung et al., 2006). The degree of symptoms that result from an acute exposure to provocative stimuli varies with the intensity of the stimulus and the person’s susceptibility (i.e., past history of motion sickness) to this condition (Hutchins & Kennedy, 1965).

For people who are susceptible to SS, the effects are cumulative and can include general discomfort, fatigue, headache, eyestrain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, fullness of head, blurred vision, dizziness, vertigo, stomach awareness, or burping (Allen, Park, Fiorentino, Rosenthal, & Cook, 2006; Kennedy, Fowlkes, Berbaum, & Lilienthal, 1992). Because drivers are compromised when experiencing these symptoms, an important aspect of simulator use is to monitor SS by using the Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1992). This questionnaire is the gold standard used to measure SS.

Simulator Sickness Etiology Theories

SS occurs when a person is exposed to moving visual scenes while the body remains in a relatively fixed state (Hettinger et al., 1990), but the precise etiology of SS remains largely unknown. The classic sensory conflict explanation, posed by Reason and Brand (1975), suggests that SS is triggered when the brain interprets sensory messages regarding movement as inharmonious. These messages are delivered by the parts of the nervous system that detect motion: the vestibular receptors; the eyes; and proprioceptors in the muscles, tendons, and ligaments. These incoming signals may also conflict with the brain’s positional memory, meaning that the brain continues to process its original position even when the body has moved to a different position (Oman, 1990).

Significance and Purpose

Driving simulators may provide an efficient, productive, and safe alternative to on-road testing and allow occupational therapists and occupational therapy researchers to conduct driving assessments, remedial sessions, or driving research in a controlled environment. Study participants, however, have demonstrated SS symptoms and an inability to complete study protocols or training sessions because of the SS (Shechtman et al., 2007). Moreover, evidence for controlling or alleviating SS in a driving simulator is not well documented in the literature.

With participants experiencing SS in our driving simulator studies and to better understand SS, we have (1) conducted a review of the literature on the etiology of SS with driving simulators; (2) used an evidence-based classification from the American Academy of Neurology’s (AAN) classification criteria (Table 1) to summarize primary studies; and (3) made evidence-based conclusions for clinical practice and research. The following sections describe the outcomes of these three objectives.

Method

Research Team

A research team with combined experience in driving simulator research and evidence-based literature reviews conducted this review. The researchers included three PhD-level researchers. We also consulted with the university’s health sciences reference librarian for aspects of the literature search.

Procedure

We assembled, critically appraised, and synthesized the results of investigations addressing SS as a result of using
Table 1. American Academy of Neurology Criteria for Rating a Study by Class and Making an Evidence-Based Recommendation (Edlund, Gronseth, So, & Franklin, 2004)

<table>
<thead>
<tr>
<th>Rating article by class</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evidence is provided by</td>
<td>Evidence is provided by</td>
<td>Evidence is provided by</td>
<td>Any design in which the test is not applied in an independent assessment OR evidence is provided by the expert opinion alone or in descriptive case series (without control participants).</td>
<td></td>
</tr>
<tr>
<td>a prospective study in a broad spectrum of people with the suspected condition using a gold standard (SSQ) for the case definition. Tests should be applied in a blinded assessment. All people undergoing the test have the presence or absence of the condition.</td>
<td>a prospective study of a narrow spectrum of people (N &lt; 100) with the suspected condition or a retrospective study of a broad spectrum of people with an established condition using a gold standard (SSQ) compared with a broad spectrum of control participants.</td>
<td>a retrospective study in which either people with the established condition or control participants are of a narrow spectrum (N &lt; 100). The reference standard, if not objective, is applied by someone other than the person performing the test.</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Rating by recommendation</th>
<th>Level A</th>
<th>Level B</th>
<th>Level C</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommendation: Established as effective, useful, or predictive, or not. &quot;Should be done, or should not be done.&quot;</td>
<td>Recommendation: Probably predictive or not. &quot;Should be considered, or should not be considered.&quot;</td>
<td>Recommendation: Possibly predictive or not. &quot;May be considered, or may not be considered.&quot;</td>
<td>No recommendation</td>
<td></td>
</tr>
</tbody>
</table>

| Condition for rating by recommendation | Class 1 study or one Class 1 study in which the magnitude of the effect is large and all criteria have been met. | Requires at least one Class 1 study or two consistent Class 2 studies. | Requires at least one Class 2 study or two consistent Class 3 studies. | Data are inadequate or conflicting. Given the current knowledge or test, the treatment is unproven. |

Note. SSQ = Simulator Sickness Questionnaire.

Inclusion and Exclusion Criteria. One of the researchers (Bewernitz) screened the sources by title and abstract to include studies containing the keywords described in the search terms. The inclusion criteria were as follows: (1) articles or primary studies published in English, (2) SS noted as a problem in the studies and served as a specific outcome variable in the study, and (3) focus on a driving simulation rather than a flight or nondriving virtual reality simulation. The published peer-reviewed articles that met the criteria were obtained through online retrieval; library access; and collections from the University of Florida's Institute for Mobility, Activity and Participation's driving library. The initial article search revealed 88 articles that used the term simulator sickness. Of those 88, only 19 were included for full-text review because they discussed SS in an automobile driving simulator. On review of the 19 full-text articles, only 10 went beyond merely mentioning SS and actually investigated SS as a main outcome variable. Thus, 10 studies that met our inclusion and exclusion criteria were included in this review.

Rating the Evidence and Making Recommendations. We selected and rated the studies using a level-of-evidence system that was based on criteria from AAN (Edlund, Gronseth, So, & Franklin, 2004; see Table 1). Study strength is indicated by Arabic numerals, with 1 being the strongest level of evidence and 4 being the weakest level of evidence. The cutoff scores were as follows: Class 1 studies or one Class 2 study or two consistent Class 3 studies. The initial article search revealed 88 articles that used the term simulator sickness. Of those 88, only 19 were included for full-text review because they discussed SS in an automobile driving simulator. On review of the 19 full-text articles, only 10 went beyond merely mentioning SS and actually investigated SS as a main outcome variable. Thus, 10 studies that met our inclusion and exclusion criteria were included in this review.

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Table 2. Evidence Table for Simulator Sickness Literature Review

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Study Objectives</th>
<th>Occupational Therapy Practice Framework</th>
<th>Design/Participants/ Simulator</th>
<th>Simulator Sickness Findings</th>
<th>Level of Evidence/ Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen et al. (2006)</td>
<td>To develop a personal computer-based program in conjunction with developing a driving simulator for older driver retraining</td>
<td>Client Age, Context and Environment, Graphics, scenario design, and duration</td>
<td>2 groups, experimental, no randomization N = 118 (n = 67 ages 70–90; n = 51 ages 21–50) with a valid driver’s license and a ≥5 yr driving experience Desktop, fixed base, 3-monitor configuration with 135° FOV</td>
<td>The younger group had a 14% dropout because of SS. The older group had a 37% dropout because of SS. Participants dropped out of the study after scenes with clear horizons and high visual detail. Changing the scenarios by decreasing the visual “choppiness” of graphics on the simulator screen, adjusting visual details, decreasing simulation duration, and putting scenes with the most maneuvers at the end decreased the incidence of SS.</td>
<td>Class 2 Gold-standard measurement, prospective study, no randomization</td>
</tr>
<tr>
<td>Lin, Parker, Lahav, &amp; Furness (2005)</td>
<td>To determine whether cues that permit prediction of vehicle turns influence SS</td>
<td>Context and Environment, Scenario design</td>
<td>1 group within-participants N = 12: 7 women, 5 men ages 18–55 with no history of auditory disturbance, balance disorders, back problems, or high susceptibility to motion sickness Real Drive cab configuration with 220° horizontal FOV</td>
<td>When inconspicuous cues or “paths” were used to provide prediction of turns, there was a statistical significant reduction of SS (repeated measures ANOVA,  F[2, 22] = 4.32, p = .026).</td>
<td>Class 4 No gold-standard measurement, prospective study, small sample size, within-participants comparison</td>
</tr>
<tr>
<td>Liu et al. (1999)</td>
<td>To find out how a “typical” driving population would perform on the DriVR simulator</td>
<td>Client Age</td>
<td>8 groups, experimental N = 148: grouped by age and balanced by gender 14 participants were unable to complete testing because of SS. Fixed-base DriVR, 30° FOV</td>
<td>Reported SS symptoms increased significantly with age in a DriVR simulator: Pearson χ² (16) = 27.55, p &lt; .05.</td>
<td>Class 2 (no gold-standard measurement, prospective study, no randomization)</td>
</tr>
<tr>
<td>Min et al. (2004)</td>
<td>To quantify SS as a bias factor, on the basis of psychophysiological measures</td>
<td>Activity Demands, Client’s length of time in simulator; psychological vs. physiological measures or SS</td>
<td>1 group, pre–post N = 20: healthy adults (10 men and 10 women) from ages 20–28 3D graphic open cab simulator LCD projector providing 30° × 50-in. FOV onto an 80-in. rear projection screen</td>
<td>SSQ scores increased 10 min into the “drive” and then more gradually as time passed: t-test (p &lt; .05). Physiological responses (per EEG, ECG, and GSR) of SS occur before psychological awareness.</td>
<td>Class 3 (gold-standard measurement, prospective study, small sample size, no comparison group)</td>
</tr>
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<tr>
<td>Mourant et al. (2007)</td>
<td>To investigate the onset of SS in 4 simulated environments: country, suburban, city, and curves</td>
<td>Context and Environment Scenario design</td>
<td>1 group, experimental N = 16: 8 men, 8 women (50–65 yr) with valid driver’s licenses who drove approximately 5,000 mi in the last year Fixed base, cab configuration, 45° FOV</td>
<td>SSQ scores increased significantly after participants experienced the 8 driving trials (Wilcoxon matched pairs test, p &lt; .01). When driving on straight roads, participants reported less SS than driving in the city with left and right turns and curves (Wilcoxon matched pairs, p &lt; .01).</td>
<td>Class 2 (gold-standard measurement, prospective, small sample size)</td>
</tr>
<tr>
<td>Mourant &amp; Thattacherry (2000)</td>
<td>To investigate SS in a fixed-base virtual environment driving simulator</td>
<td>Client Gender Context and Environment Scenario design (rural vs. highway vs. city) Activity Demands Client postural stability changes because of simulator interaction</td>
<td>3 groups, experimental N = 30: 15 men and 15 women aged 18–36 randomly assigned to 3 groups (highway, rural, or city scenarios) Virtual Research 8, 60° FOV</td>
<td>Participants driving rural road environments had more difficulty with postural stability symptoms than those driving in the city environments (p &lt; .05). Difference between before and after occulomotor scores were significant (highway, p &lt; .05; rural, p &lt; .05; city, p &lt; .01). Before the tests, women had less postural stability than men (p &lt; .005) and more declines in postural stability (p &lt; .01) after simulated driving. All comparisons used paired t tests.</td>
<td>Class 2 Gold standard measurement, prospective study, small sample size</td>
</tr>
<tr>
<td>Park et al. (2006)</td>
<td>To describe the incidence and severity of SS found in an older driver simulation study</td>
<td>Client Gender Context and Environment Scenario design</td>
<td>2 groups, experimental, no randomization N = 118 (n = 67 ages 70–90; n = 51 ages 21–50) with a valid driver’s license and a ≥5 yr driving experience Desktop, fixed base, 3-monitor configuration with 135° FOV</td>
<td>2 groups were analyzed separately: dropout group and nondropout group. Analyses of both groups was a 2 × 2 × 5 mixed ANOVA (within variables: age, gender; between variables: baseline and postrun SSQ scores) Dropout group (dropped out because of SS)—main effect for each SSQ measure:  - Nausea: F(4, 80) = 19.58, p &lt; .001  - Oculomotor: F(4, 80) = 8.58, p &lt; .001  - Disorientation: F(4, 80) = 9.59, p &lt; .001</td>
<td>Class 2 Gold standard measurement, prospective study, no randomization</td>
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<tr>
<td>Park et al. (2004)</td>
<td>To describe SS when using a PC-based platform on 3 different display and hardware configurations</td>
<td>Client Gender Context and Environment Type of configuration</td>
<td>3 groups, experimental, no randomization $N = 493$ (269 women and 224 men, ages 14–18) 3 different configurations (all fixed base with PC STISIM Drive software); single monitor, 60° FOV; 3-monitor, 135° FOV; Vehicle cab, 135° FOV Differences for SSQ scores by configuration type, $F(2, 487) = 30.49$, $p &lt; .001$, using $3 \times 2 \times 6$ mixed ANOVA (between participants factors configuration type, gender; within participants factor 6 training trials). The single-monitor configuration provided the largest percentage of SS (13.68%), followed by the vehicle cab (5.31%) and the 3-monitor system (0.62%). Women reported more SS during the early stages of the drive, $F(5, 2435) = 4.08$, $p = .001$.</td>
<td>Class 2 No gold standard measurement, prospective study, no randomization Conclusion Client: Women are probably more susceptible to SS than are men. Context and Environment: When using vehicle cab and single-monitor configurations, clients will probably experience more SS than in a 3-monitor configuration.</td>
<td></td>
</tr>
<tr>
<td>Reed-Jones et al. (2008)</td>
<td>To evaluate the relationship between SS symptoms and postural stability in a driving simulator</td>
<td>Activity Demands Postural stability after simulator assessment</td>
<td>3 groups, experimental $N = 30$ (12 men and 18 women, ages 18–22) randomly assigned to a no-intervention group in the simulator, a group receiving electrical stimulation of the vestibular nerve while driving, and a group who received electrical stimulation cutaneously on the neck while driving Drive Safety DS-600c, fixed base Postural stability is negatively correlated to SS. People with SSQ scores &lt;15 (those who did not experience severe SS) had the greatest decrease in postural stability after VE simulation ($p = .007$). Application of a secondary vestibular or cutaneous stimulation required more visual compensation for postural control.</td>
<td>Class 2 Gold standard measurement, prospective study, small sample Conclusion Activity Demands: Application of secondary sensory stimulation probably affects postural stability and demands more visual compensation.</td>
<td></td>
</tr>
</tbody>
</table>
The study design, sample description, type of simulator used, SS findings, level of evidence, and the study authors’ conclusions regarding the SS findings. This matrix serves as a data extraction guide that was used to synthesize the findings regarding SS.

**Results**

**Descriptive Profile of the Primary Studies**

Ten articles published from 1999 to 2008 were included for primary analysis. Sample sizes from the articles ranged from 12 to 493. The studies represented research in three countries: the United States, Canada, and South Korea. Of the studies reviewed, 6 explored, by our definition, client factors; 7 discussed context and environment factors; and 3 discussed activity demands. Because overlap was possible, the studies were not mutually exclusive in addressing each of the factors. Seven of the 10 articles indicated an external funding source.

**Level of Evidence**

On the basis of our review and assigned levels of evidence, 8 of the 10 articles reviewed provide Class 2 evidence, 1 provides Class 3 evidence, and 1 provides Class 4 evidence (Edlund et al., 2004). Table 2 provides an evidence-based synopsis of the primary studies included in this literature review.

**Evidence-Based Recommendations**

**Client Factors**

**Result**: This review yielded 6 Class 2 studies focusing on client factors (Allen et al., 2006; Liu, Watson, &
Miyazaki, 1999; Mourant & Thattacherry, 2000; Park, Allen, Fiorentino, Rosenthal, & Cook, 2006; Park et al., 2004; Reed-Jones, Vallis, Reed-Jones, & Trick, 2008).

**Conclusion.** From these studies, we concluded that age and gender probably contribute to SS symptoms with older participants. Participants who were age 70 and older experienced statistically significantly more SS symptoms than did those age 50 and younger. Women also experienced statistically significantly more SS symptoms than men. As such, age and gender should probably be considered factors contributing to SS in occupational therapy practice and research.

**Recommendation: Level B.** A Level-B recommendation was made for evidence regarding client factors (old age and female gender). All 6 of the studies reviewed provided Class 2 evidence. More prospective experimental studies using larger sample sizes, randomization, and control groups are necessary to provide conclusive evidence on age and gender. In addition, longitudinal studies may be useful to determine whether SS is an aging by-product or simply a cohort effect.

**Context and Environment Factors**

**Result.** This review yielded 6 Class 2 studies focusing on context and environment as they relate to SS (Allen et al., 2006; Mourant, Rengarajan, Cox, Lin, & Jaeger, 2007; Mourant & Thattacherry, 2000; Park et al., 2004, 2006; Seay, Krum, Hodges, & Ribarsky, 2001) and 1 Class 4 study (Lin, Parker, Lahav, & Furness, 2005).

**Conclusion.** Many aspects of the virtual simulated environment contributed to decreasing SS, including decreasing the visual “choppiness” of graphics by increasing the refresh rate of the information on the simulator screen; using atmospheric fog in the scenarios to decrease the visual impact of a clear horizon or to decrease the impact of scenarios with complex visual detail; changing the order in which scenarios were run, such as starting with less visually complex scenarios and progressing to scenarios with more detail; changing the duration of the scenarios; and changing the road geometry, such as starting scenarios with a straight path and progressing to scenarios that involve curves and turns (Allen et al., 2006; Mourant et al., 2007).

Likewise, uncalibrated mechanical parts of a simulator (e.g., delayed time between pressing the brake and actually coming to a stop) may contribute to increases in rates of SS. The actual type and configuration of the driving simulator used also contributed to increases in SS rates. For example, participants using a 6-ft × 8-ft single-monitor 60° field of view configuration experienced SS (Seay et al., 2001), whereas those in another study using single-desktop or three-screen configurations (Park et al., 2004) did not. A caveat of this 6-ft × 8-ft single-screen 60° field of view simulator is that the immersive environment, while making participants feel more “present” in scenarios, also increases the likelihood of experiencing nausea or other SS symptoms (Seay et al., 2001).

**Recommendation: Level B.** Factors related to context and environment (i.e., graphic refresh rates, scenario design and duration, simulator configuration and calibration) probably affect the rates of SS, because 6 of the studies provide Class 2 evidence. Randomized controlled trials (RCTs) using driving simulators are necessary to further support the effect of the environmental factors on SS.

**Activity Demands**

**Result.** This review yielded 2 Class 2 studies related to activity demands (Mourant & Thattacherry, 2000; Reed-Jones et al., 2008) and 1 Class 3 study (Min, Chung, Min, & Sakamoto, 2004).

**Conclusion.** The visually induced illusion of motion when one is actually still, also called vection, is a necessary precondition for SS (Kennedy et al., 1992). Participants who drove at higher speeds demonstrated greater vestibular challenges, indicating that high speeds in a simulator may contribute to SS (Mourant & Thattacherry, 2000). Reed-Jones and colleagues (2008) found that application of a secondary sensory stimulation (vestibular or cutaneous) resulted in increased visual dependency for maintaining postural control after simulated driving. This finding suggests that sensory interactions during simulated driving may contribute to postural instability that is observed after simulation in a virtual environment and is related to how visual information is used to control posture.

**Recommendation: Level C.** We make a Level C recommendation for the impact of activity demands on SS symptoms because we did not find consistent Class 2 findings for each component. Therefore, driving at high speeds in a simulator possibly contributes to SS symptoms, as does the increase in postural instability during simulated driving. For occupational therapy researchers who investigate SS, we recommend studies using larger representative samples with control groups to strengthen the level of evidence for activity factors like vection, driving speed, and the effects of postural instability on SS.

**Discussion**

Using the AAN’s classification criteria for evidence-based reviews, we summarized the findings from 10 published studies to report the level of evidence for factors contributing to SS in a driving simulator. On the basis of the
level of evidence offered by each study, we identified conclusions regarding SS and provided recommendations. These results contribute to the SS literature by presenting evidence-based findings.

We did not identify any Class 1 studies addressing SS in a driving simulator; therefore, no Level A recommendations could be made. This finding was surprising because driving simulators are perfect for conducting studies under repeatable and controlled conditions. A need exists to determine, through RCTs, the causes of SS.

Two Level B recommendations were made, because 2 consistent Class 2 studies were identified in the “client” and “context and environment” domains. The studies indicate that the identified “client” and “context and environment” factors are probably predictive of SS. A Level C recommendation was made because the identified “activity demands” (vection, speed of driving, and postural instability) possibly contribute to SS during simulated driving.

This study was conducted as an etiological (i.e., examining the determinants of SS), evidence-based review following predetermined criteria. Our study has limitations. We included only studies written in English, we did not search the “gray” literature (e.g., government reports), and we did not backtrack reference lists in the articles that we used. We used team consensus, rather than rater reliability, to select and rate the primary studies and did not control for publication bias by seeking unpublished manuscripts (Cooper & Hedges, 1994). Simulator research is ongoing, and we may not have captured every primary study investigating SS in this review. This study is the first, however, that summarizes the literature on determinants of SS in a way suitable for clinical decision making and identifies areas in which further research is needed.

Clinical Implications
Driving simulators are used in occupational therapy practice and research, and they provide a safe alternative to on-road testing (Davidse, 2007; Freund & Colgrove, 2008; Lee et al., 2003; Shechtman et al., 2007, 2008). They also allow occupational therapists to conduct driving assessments or remedial sessions in a controlled environment (Stern & Schold Davis, 2006). Therapists, however, need to be aware of and able to reduce SS symptoms. From our evidence-based conclusions and recommendations, we have established several clinical implications. First, client factors, such as being of older age (>70) or being female, probably contribute to experiencing SS symptoms. Second, environmental factors, both virtual and mechanical, probably promote SS symptoms. Virtual environmental factors include low refresh rates on the simulator screen, complex visual detail in the scenarios, duration of the scenarios, and curves and turns. Mechanical environmental factors that probably contribute to SS include poor calibration of the mechanical parts of the simulator as well as the type and configuration of a simulator (i.e., car cab representing an immersive environment vs. desktop simulators). Third, client–environment factors, such as a client driving at high speeds or experiencing postural instability, possibly contribute to SS. Thus, clinicians must yield to the previously mentioned factors and execute caution when selecting clients to be tested in a driving simulator.

Research Implications
We have identified a need for well-designed RCTs to clearly show the impact of underlying factors on the occurrence of SS. Factors include client factors (e.g., age and gender), context and environment factors (e.g., virtual scenes and calibration of mechanical parts), and activity demands (e.g., a participant driving at high speeds in a rural scenario or postural stability changes because of simulated driving). Such studies will reveal the effects of SS on simulated driving performance and help occupational therapists provide best practices for their clients receiving driving rehabilitation services in a simulator. Moreover, conducting such studies will conclusively address the causes of SS; only then can effective SS mitigation strategies be developed and tested. ▲

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