Lessons Learned Regarding Simulator Sickness in Older Adult Drivers

Nicholas D. Cassavaugh, Joshua E. Domeyer, and Richard W. Backs

Centeral Michigan University Center for Driving Evaluation, Education & Research

Abstract. The present paper examines simulator adaptation syndrome (SAS) as a barrier to simulator use for older adults. A brief description of the phenomenon is provided and its history discussed. There are generally three domains in which to make changes to alleviate the problem. Changes to the simulator, the scenarios, and the participants are viable avenues to reducing the effects of SAS. The experiences of the author's attempts to deal with high attrition rates among older adults in research and in a driving evaluation scenario are described and successful strategies are presented.

Keywords: Aging, Driving, Simulation.

1 Introduction

The number of U.S. licensed drivers who are over the age of 65 rose by about 6 million between 1998 and 2008. This trend is expected to continue as drivers in the "baby boomer" generation reach retirement age. One of the difficulties of this rapid increase in age is that the associated cognitive declines [1-8] may affect driving performance. Initially, researchers feared that the confluence of the increase in the population of older drivers and age-related cognitive declines could lead to an increase in traffic-related deaths and injuries. This led to an increase in research on driving performance of older adults. Although some recent research suggests that reduced driving abilities in older adults may not be as great a problem as originally feared [9], researchers have found it incumbent upon themselves to determine the severity of the effects of age-related decreases in cognitive abilities on driving performance.

In recent years, driving simulators have become more and more prevalent in driving research. Increased in simulator fidelity, as a consequence of advancing computing technology, has played a significant role in the rise of simulator use. These technologies are particularly useful for driving evaluations. For instance, in on-road evaluations traffic density differs greatly by time of day, even over the same route, making it nearly impossible to obtain a consistent evaluation across clients. Further, it is both unethical and dangerous to lead clients into dangerous traffic situations in order to test reaction times. Finally, if a person's driving ability is in question, it may be difficult to conduct an on-road driving evaluation and maintain safety requirements.

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1.1 Motion Sickness and Simulator Sickness

Money [10] described motion sickness as a condition brought on by exposure to motion stimuli and most frequently characterized by the experience of pallor, cold sweating, nausea and vomiting. Benson [11] noted that motion sickness is an all-inclusive term which subsumes sicknesses named for the respective environments or vehicles which provoke it (e.g., carsickness, seasickness). Simulator sickness, or simulator adaptation syndrome (SAS) as it will be referred to here, is a type of motion sickness in which the absence of motion leads to motion sickness symptoms. SAS is an unfortunate side effect of using simulators with less than full motion capabilities. As is commonly noted in the literature, SAS was first written about by Havron and Butler in 1957 [12] with a military helicopter simulator.

Much of the early research on simulator sickness used military flight simulators, because other types of simulators were not in use until relatively recently. Indeed, much of our understanding of how to avoid simulator sickness comes from studies in flight simulators. Reducing lag times between motion cues and visual cues [13], limiting field of view [14], reducing the visual complexity of the simulation [13] and increasing the frame rate of the display are all effective techniques to reduce SAS. However, some methods can severely limit the utility of the simulator. For instance, in a driving simulator reducing the forward field of view from 150° to only 50° can eliminate views of the left and right approaches to an intersection. Reducing visual complexity by eliminating scenery items or ambient traffic may limit the ecological validity of the simulation.

A 1985 review by Kennedy and Frank [15], citing Benson, noted that motion sickness effects decreased with age, all but disappearing after the age of 50 years-old. Benson noted that the age-related decrease in susceptibility to motion sickness might be due to long-term adaptation. That is, older adults have had more exposure to riding in moving vehicles and this exposure may be responsible for their reduced susceptibility. However, recent work suggests that older adults (over the age of 65 years) may be *more* susceptible to SAS than younger adults [16]. Indeed, the authors have noted considerable attrition among older participants in several studies which indicate that SAS presents a significant problem for driving simulation.

For example, while working on a simulator research project in graduate school, the first author and his colleagues pilot-tested a collision-avoidance scenario on a post-doctoral fellow who experienced severe nausea and was subsequently nauseated for half a day recovering. This occurred in spite of the fact that he reported no prior experience with motion sickness of any kind. Any measure that can be taken to reduce these symptoms should be taken, particularly with clients seeking driving evaluation.

2 Remedies

Having outlined the issues and problems involved in utilizing simulators, we now turn to ways to avoid this problem. There are at least three general means to this process: changes to the simulator, changes to the scenarios, and changes to the participant/client. Each approach is discussed briefly.

2.1 Changes to the Simulator

First, we will discuss changes to the simulator. The simulator itself can induce sickness due to a disconnection between the real world and the virtual world. That is, a difference between the visual motion cues (virtual world) and the absence of vestibular motion cues (real world). One issue with the images of most low-cost simulators is that they are displayed by standard projectors or flat-screen displays. While they do provide high-resolution images, the displays are usually only veridical from a specific viewpoint. For instance, in a simulator that uses a built-up cab (BUC) with a passenger seat, conducting research with a passenger in the vehicle can be difficult. Anecdotal evidence suggests that the non-veridical view of the scene from the passenger's seat can increase the likelihood of simulator sickness in the passenger. Similarly, differences in the driver's head position while conducting some secondary task could produce simulator sickness effects (although to a lesser extent than in the first example). This problem can be alleviated by the use of collimation. Collimated light is light whose rays are nearly parallel to one another and therefore spread minimally over distance. Indeed, many high-end simulators, particularly full-flight simulators used in aviation, use collimated optics. Because the light in the image is composed of parallel rays, the image appears "correct" to a viewer in any position, thus solving this particular problem. However, the use of collimation in a simulator significantly increases the cost and the space requirements. A large collimating mirror is generally required and must be positioned such that it encompasses the entire visual field at sufficient distance from the viewpoint. The added cost and space of collimation are barriers to implementation and most commercially available driving simulators do not include this as an option.

On the other hand, many simulators do offer some degree of motion platform to provide the missing vestibular motion cues to go with the visual motion cues. Perhaps the most visible example of this is the National Advanced Driving Simulator (NADS) in Iowa City, Iowa. The motion platform in use at NADS boasts a 13-degree of freedom motion platform which moves about a 64x64 foot bay to provide true acceleration cues [17]. Researchers using the NADS have reported a 2% simulator sickness rate [18], which is a significant improvement over the 50% or so rate of attrition encountered in some cases by the present authors. However, it is clear that even with such an advanced simulator, the problems of motion sickness are not completely eliminated.

While collimation and motion platforms can do a very good job at reducing simulator sickness, for the most part these are expensive options. Further, as we have seen they do not guarantee success. It is probably fair to say that most research and clinical facilities do not have the funds to purchase and operate simulators of the size and complexity of the NADS. Luckily, there are still a number of approaches involving scenario design and participant interactions which can be taken to minimize the problem.

Another potential change which seems to help anecdotally is adding cooling fans or air conditioning vents to the cab. One of the main symptoms of SAS is elevated temperature and sweating. A cooling fan or room A/C vented into the simulator cab can help participants feel cooler and therefore less symptomatic.

2.2 Changes in Scenario Design

In terms of scenario design, there are several dimensions which one can manipulate to reduce the likelihood of simulator sickness. These dimensions include the duration of the scenario, the visual complexity of the scenario, and the topographical layout of the scenario (i.e., straight roads, curvy roads, 90° turns). In our initial attempt at a driving evaluation scenario, we created a scenario which lasted approximately 25 minutes and took the participant on winding country roads, onto freeways, into residential roads and back onto the freeway. This long, all-inclusive scenario was later dubbed a "monolithic" approach. A considerable number of participants were not able to complete this long drive and dropped out due to simulator sickness. In contrast, our present approach is to have a number of discrete, self-contained scenarios which capture one to three specific driving behaviors in very short scenarios, typically less than five minutes in duration. After each scenario, the simulation is stopped and the participant rests while the experimenter performs the tasks necessary to start the next scenario. This provides for a respite from the conflicting sensory information and for a period of recovery before continuing to the next scenario. We have found this to work well for our application in driving evaluation.

Scenery changes are also a useful approach. When a scenario includes scenery which is plentiful and located close to the roadway as is the case in an urban area, there is a consequent increase in the amount of optic flow information. Optic flow is the pattern of apparent motion of scenery objects as a result of motion of the viewpoint. Increased optic flow has been shown to be related to simulator sickness [19]. This conforms to the predictions of sensory conflict theory [20]. Increased visual cues in the absence of vestibular cues mean more sensory conflict and therefore more sickness. Similarly, faster speeds and turns and/or curves mean more optic flow and can thus produce more symptoms of sickness. Thus, unless the situation specifically calls for it, we avoid urban settings, turns, and scenery close to the roadway. Of course driving evaluation is not complete without turns and highway driving. Because these are necessary components of an evaluation, but known to cause symptoms of simulator sickness, we leave the scenarios of the evaluation that involve urban areas and turning until the end of the protocol. This ordering of scenarios gives the person greater opportunity to adapt to the simulator under conditions least likely to evoke symptoms. When coupled with short scenarios and breaks between them, this ordering has proven to be a useful strategy to minimize SAS.

2.3 Characteristics of the Individual

One potentially useful approach to simulator research with older adults is to develop a pool of older adults who are able to tolerate the simulator. While this is certainly convenient, there are two rather obvious problems with this approach. First, there is sampling bias introduced in a research sample selected by this approach. Second, driving evaluations are performed for paying clients, who expect to be able to have a complete evaluation performed.

Other approaches to reduce SAS may also be employed, such as medication for motion sickness, or even placebo treatments such as the use of wrist-pressure bands. These methods are less than ideal. Asking participants/clients to take medication prior to their experience in the simulator may actually prime them to experience sickness [21]. In addition, there may be issues of liability involved as some motion sickness medications may not be compatible with the an individual's medication regimen. Placebo treatments are only as effective as the user believes them to be and are therefore not a reliable means to reduce SAS. It should be noted that medications that are intended to reduce the effects of motion sickness (e.g., Dramamine) can have undesirable side effects which may skew the results of evaluations or research [22, 23].

In our experience, however, the most effective approach to reducing simulator sickness harkens back to Benson's [11] proposal that long-term adaptation is responsible for lower rates of motion sickness in older adults. We have found that providing exposure to driving in the simulator in short durations and over time reduces simulator sickness in older adults. Results from several studies have shown decreased simulator sickness symptoms with repeated exposure within and between days [24-27]. This reduction in simulator sickness symptoms due to time delay between simulator sessions has been shown to persist up to a month or longer [25]. Howarth and Holder [24] found that simulator sickness symptoms decreased over 10 days of simulator exposure with a session on each day. Teasdale et al. [27] found that older adults' (ages 65 to 84 years) simulator sickness symptoms decreased over subsequent simulator sessions. They found that older adults acclimated to simulation over several sessions. After the fifth session the older adults did not differ from the initial baseline condition on simulator sickness scores. These studies indicate that a time delay and adaptation could be used to attenuate simulator sickness symptoms as measured by a subjective questionnaire.

2.4 Our Driving Center's Approach

Our current approach involves a two-day evaluation protocol with a lag day between them. Each day starts with a brief adaptation scenario which lasts about 15 minutes or so. The participant or client drives a series of drives along straight roads with little to no scenery. The session ends with practicing left and right turns at an intersection. These practices consist of a single turn after which the simulator stops and, depending on performance, may be restarted as many times as necessary for the participant/client to attain a level of proficiency at making turns. Indeed all of the adaptation scenarios are repeated as often as the participant requests. The remainder of the first day is spent doing other testing. On the second day there is about a 1-hour period of testing between the adaptation and the final hour which is spent in the simulator performing the evaluation scenarios.

To date, we have had greater success with this approach in experimentation and have had zero attrition from paying clients. We adopted this procedure before opening the center to paying clients, so there is no means of comparison. Although the clients are essentially self-selected, they are generally not there to be evaluated because they want to be there --- they are there because family members are concerned about their driving. Our approach has also worked with clients who have co morbidity issues such as Parkinson's disease.

In order for an adaptation protocol to be amenable to research and client evaluation schedules, it needs to be well defined and it must lead to the most beneficial outcomes for the given amount of time. This means that it is necessary to define the number of exposures, time between exposures, and persistence of the adaptation in order to maximize SAS attenuation. Fortunately, SAS research conducted with other simulators shows reduced symptoms over multiple exposures sometimes resulting in plateau effects [24, 25]. Still, this research needs to be more precisely identify which SAS adaptation delays are most appropriate for research and evaluation schedules. For instance, if two days of adaptation results in significant reductions in SAS symptoms and attrition but subsequent days only result in marginal gains it would be more beneficial to use a two-day adaptation. Another obstacle to implementing a SAS adaptation protocol is determining the persistence of adaptation. Hu & Stern [25] found that adaptation could last well over a month. Examining these characteristics of an adaptation protocol would help find the most beneficial way to increase the well-being of research participants and clients.

One source of confusion in determining the likelihood of withdrawal from a simulator study or evaluation is a number of differences in the attrition rate between research participants and evaluation clients. In a research situation, we were able to find an age-related trend in attrition (Domeyer, Cassavaugh, & Backs, in preparation) but with evaluation clients we have not experienced any withdrawal. This result corresponds to accounts from other researchers who do work with driving simulators and may be attributed to several factors. First, there are differences in the motivation to complete between research participants and evaluation clients. Clients have more at stake considering that, many times, the evaluation is used by a physician to determine driving fitness, whereas research participants are paid by the hour for their participation. Second, participants may base their choice of withdrawal on something besides the primary indicators of symptoms. Alternative symptoms, such as fatigue, may play a greater role in a participant's reaction to the simulator. Unfortunately, these factors make it difficult to determine whether a reduction in SAS symptoms will reduce attrition in research. Indeed, the goal of much of the research into SAS should be to reduce the symptoms and consequently the withdrawal rate regardless of the status of the individual as a participant in research or an evaluation client.

3 Conclusions

It seems clear to us that the protocol at our facility using habituation in the form of relatively short adaptation scenarios performed over two days is a highly effective way to ensure that older adults have access to simulation facilities. In conjunction with changes to the scenarios discussed above, this protocol seems to provide the greatest effect on reducing SAS at the lowest cost. Increased access to simulator-based driving evaluation and simulator-based driving research will help older adults maintain driving independence longer and to be safer while doing so.

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