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Dropout during a driving simulator study: A survival analysis

Nicole A. Matas, * Ted Nettelbeck, Nicholas R. Burns

School of Psychology, University of Adelaide, South Australia 5005, Australia

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ABSTRACT

Introduction: Simulator sickness is the occurrence of motion-sickness like symptoms that can occur during use of simulators and virtual reality technologies. This study investigated individual factors that contributed to simulator sickness and dropout while using a desktop driving simulator. *Method:* Eighty-eight older adult drivers (mean age 72.82 ± 5.42 years) attempted a practice drive and two test drives. Participants also completed a battery of cognitive and visual assessments, provided information on their health and driving habits, and reported their experience of simulator sickness symptoms throughout the study. *Results:* Fifty-two participants dropped out before completing the driving tasks. A time-dependent Cox Proportional Hazards model showed that female gender (HR = 2.02), prior motion sickness history (HR = 2.22), and Mini-SSQ score (HR = 1.55) were associated with dropout. There were no differences between dropouts and completers on any of the cognitive abilities tests. *Conclusions:* Older adults are a high-risk group for simulator sickness. Within this group, female gender and prior motion sickness history are related to simulator dropout. Higher reported experience of symptoms of simulator sickness increased rates of dropout. *Practical applications:* The results highlight the importance of screening and monitoring of participants in driving simulation studies. Older adults, females, and those with a prior history of motion sickness may be especially at risk.

Driving simulators are becoming more widely available and these instruments have many useful applications for research, training, assessment, rehabilitation, and entertainment (Allen, Rosenthal, & Cook, 2011; Classen & Brooks, 2014; Crisler et al., 2011; Dickerson, Meuel, Ridenour, & Cooper, 2014; Pollatsek, Vlakveld, Kappe, Pradhan, & Fisher, 2011). The availability of lower-cost options means that driving simulators are now increasingly accessible to researchers and therapists. Simulators have been used successfully to investigate how to improve the training of novice drivers, (Allen, Park, Cook, & Fiorentino, 2012; de Winter et al., 2009; Pollatsek et al., 2011), and for re-training older drivers and patients with acquired brain injury (Casutt, Theill, Martin, Keller, & Jäncke, 2014; Pollatsek, Romoser, & Fisher, 2012; Unsworth & Baker, 2014). They have also proved useful for investigating distractions common among on-road drivers including use of cell phones while driving (Caird, Willness, Steel, & Scialfa, 2008), text messaging (Casutt et al., 2014), and use of in-vehicle entertainment systems (Engström, Johansson, & Östlund, 2005; Horberry, Anderson, Regan, Triggs, & Brown, 2006); and, more generally, for monitoring driver responses to challenging driving situations (Bélanger, Gagnon, & Yamin, 2010; de Waard, Dijksterhuis, & Brookhuis, 2009; Martin et al., 2010). They have also found wide application for studying the relationship between cognitive abilities and driving performance (Bélanger et al., 2010; Hoffman, Atchley, McDowd, & Dubinsky, 2005; Shanmugaratnam, Kass, & Arruda, 2010) and the effects of cognitive interventions on driving performance (Roenker, Cissell, Ball, Wadley, & Edwards, 2003). A survey of driver rehabilitation specialists found that 11% of specialists reported successfully using a simulator as part of assessment and training procedures (Dickerson, 2013), and a meta-analysis of occupational therapy interventions found that simulator interventions were the most commonly reported and were effective for use with older adults and brain injury patients (Unsworth & Baker, 2014). Driving simulators have been effectively used in different populations, including novice drivers (Allen et al., 2012; de Winter et al., 2009), older drivers (Hoffman & McDowd, 2010; Horberry et al., 2006; Lee, Cameron, & Lee, 2003; Martin et al., 2010; Stinchcombe & Gagnon, 2013), and clinical groups including patients with cognitive impairment (Devlin, McGillivray, Charlton, Lowndes, & Etienne, 2012; Frittelli et al., 2009), HIV (Vance, Fazeli, Ball, Slater, & Ross, 2014), diabetes (Cox, Gonder-Frederick, Kovatchev, Julian, & Clarke, 2000), sleep disorders (Smolensky, Di Milia, Ohayon, & Philip, 2011), and brain injury (Lew et al., 2005; Schultheis et al., 2006).

Driving simulators have several advantages compared to an on-road driving assessment. Most importantly, they are safer than on-road driving, allow dangerous and unusual situations to be assessed, and provide a consistent and repeatable test environment. They also avoid the cost, space, and personnel requirements of on-road testing (Allen et al., 2011; Classen, Bewernitz, & Shechtman, 2011; Classen & Brooks, 2014). Potential clinical patients, physicians, and users agree that driving simulators are an acceptable tool for assessment, research, and training (Crisler et al., 2011; Gibbons, Mullen, Weaver, Reguly, & Bédard, 2014; Schultheis, Rebimbas, Mourant, & Millis, 2007). A growing body of research indicates that driving simulators provide a valid representation

* Corresponding author. Tel.: +61 8 8313 3055.
E-mail address: nicole.matas@adelaide.edu.au (N.A. Matas).

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of on-road driving behavior, depending on the equipment used and the situation being evaluated (Mullen, Charlton, Devlin, & Bédard, 2011; Shechtman, 2010). For example, driving simulator performance predicted at-fault or partially at-fault crashes in the five years following assessment (Hoffman & McDowd, 2010) and, for learner drivers, performance on a driving simulator predicted performance on an on-road assessment 6 months later (de Winter et al., 2009). Discriminant validity has been demonstrated by significant differences in the performance of non-drivers, novice drivers, and experienced drivers both on a simulator and during on-road driving (Mayhew et al., 2011). Measures of overall performance, when compared between simulator and on-road assessment, display concurrent validity across all age groups from young adults to the elderly (Engström et al., 2005; Lee, Cameron, et al., 2003; Mayhew et al., 2011). Specific aspects of driving are also related for simulated driving and on-road driving; for example, Shechtman, Classen, Awadzi, and Mann (2009) demonstrated relative validity for types of driving errors made, and Kaptein, Theeuwes, and van der Horst (1996) showed absolute validity for route choice behavior and relative validity for speed and lateral control. Furthermore, results have indicated that lower-fidelity simulators can produce results that are comparable to high cost, high fidelity simulators (Gibbons et al., 2014; Lemieux, Stinchcombe, Gagnon, & Bédard, 2014).

One of the potential disadvantages of using driving simulators is the occurrence of Simulator Sickness (SS), a well-documented side effect of using a wide range of simulators and virtual reality technology (Brooks et al., 2010; Classen et al., 2011; Johnson, 2005; Kennedy, Lane, Berbaum, & Lilienthal, 1993; McCauley, 1984; Stoner, Fisher, & Mollenhauer, 2011; Trick & Caird, 2011). Overall estimated prevalence of simulator sickness varies greatly: for example McCauley (1984) reported rates of 10–84%, and Johnson (2005) reported rates of 0–90%. Of 3691 trials on a flight simulator, 50% of all users experienced some SS (Kennedy et al., 1993). Experience of SS is related to high rates of participant dropout in driving simulator studies; Trick and Caird (2011) reported estimated dropout rates of between 35% and 75% from various institutions conducting driving simulation research with older drivers, with an average of around 40% attrition. This high dropout rate not only is a concern for users of driving simulators, but also poses an ethical challenge when seeking to recruit research participants due to simulator sickness being considered as a potential risk (Brooks et al., 2010).

Simulator sickness is usually measured through specialized self-report questionnaires, such as the Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993). The SSQ has been called the 'gold standard' for measuring simulator sickness (Johnson, 2005). Symptoms related to SS and measured by the SSQ include general discomfort, fatigue, headache, eyestrain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, feelings of fullness or pressure in the head, blurred vision, dizziness, vertigo, stomach awareness, and burping. Participants respond on a four-point scale the extent to which they are experiencing each of the 16 symptoms. The 16 symptoms form three factors: oculomotor symptoms (e.g., eyestrain), disorientation symptoms (e.g., dizziness), and nausea symptoms (e.g., nausea, stomach awareness; Kennedy et al., 1993). A short form of the SSQ, the mini-SSQ, has also been used (Mourant, Rengarajan, Cox, Lin, & Jaeger, 2007). This version was developed to avoid delays involved in repeated administration, and includes only six symptoms: general discomfort, headache, blurred vision, sweating, feeling faint, and stomach discomfort. The mini-SSQ was shown to be sensitive to changes in driving conditions (Mourant et al., 2007). Park, Allen, Fiorentino, Rosenthal, and Cook (2006) reported that higher increases in SSQ score were related to dropout, with participants who dropped out of the study displaying increased SS over time, compared to non-dropouts, whose SSQ scores remained stable over time.

Factors contributing to simulator sickness can be located within three categories: (a) factors related to the individual, (b) factors related to the simulator, and (c) factors related to the simulated task (Cassavaugh, Domeyer, & Backs, 2011; Kolasinski, 1995). Of these, the simulator and task specifications can be controlled to an extent, for example by using a motion base simulator that replicates the pitch and roll movements of a real car (Stoner et al., 2011), using shorter scenarios (Cassavaugh et al., 2011), avoiding turns (Mourant et al., 2007; Stoner et al., 2011), and reducing the field of view (Johnson, 2005; Kolasinski, 1995). Factors related to the individual are harder to control because they are often related to inherent characteristics of the person, such as age, gender, and medical history (Johnson, 2005). It is nonetheless important to recognize these factors so that steps can be taken to identify risk-factors and take appropriate steps to ensure SS is kept to a minimum.

Age has been identified as an important individual factor contributing to SS. Early reviews stated that SS occurs most frequently for ages 2–12, declines rapidly for ages 12–21, and continues to decline as age increases so that it is almost non-existent beyond age 50 (Johnson, 2005; Kolasinski, 1995). However, many of these earlier reports were based on flight simulation and older adults were not specifically considered. Based on more recent driving simulation reviews, it appears that older drivers represent a particularly at-risk group (Cassavaugh et al., 2011; Classen et al., 2011; Trick & Caird, 2011). For example, in a review of recent driving simulation studies, Classen et al. (2011) reported that drivers over the age of 70 are particularly at risk for SS, and Cassavaugh et al. (2011) noted dropout rates from simulation studies of up to 50% among older adult drivers. Several recent studies have reported dropout rates of between 0% and 44% for older adults (e.g., Bélanger et al., 2010; Brooks et al., 2010; Caird, Chisholm, Edwards, & Creaser, 2007; Domeyer, Cassavaugh, & Backs, 2013; Edwards, Creaser, Caird, Lamsdale, & Chisholm, 2004; Lee, Lee, Cameron, & Li-Tsang, 2003; Shanmugaratnam et al., 2010; Sklar, Boissoneault, Fillmore, & Nixon, 2014) and between 0% and 17% for younger adults (e.g., Bélanger et al., 2010; Domeyer et al., 2013; Shechtman et al., 2007; Yang, Jaeger, & Mourant, 2006); see Table 1 for a summary. However, estimating a reliable average dropout rate is hampered because many driving simulation studies have not reported dropout information. Additionally, dropout rates vary depending on the configuration of the simulator and the demands of the simulated task. Nonetheless, in general, results show that older adults drop out more frequently than younger adults. However, due to the small sample sizes often participating in such studies, the differences have frequently not been statistically significant.

Gender is another individual factor that is related to simulator sickness. Generally, reviews have suggested that females are more at-risk than males, especially older females (Classen et al., 2011; Johnson, 2005; Trick & Caird, 2011). Females have been reported to be more susceptible to motion sickness, simulator sickness, and visually induced motion sickness (Allen et al., 2003; Keshavarz & Hecht, 2014; Klosterhalfen et al., 2005; Mourant & Thattacherry, 2000; Park et al., 2006). Females may be particularly sensitive to simulator scenarios involving high sensory conflict and increased vection (visual illusion of self-motion) and visual flow (Jäger, Gruber, Müri, Mosimann, & Nef, 2014). Thus, females have been found to report a more severe history of motion sickness than males (Flanagan, May, & Dobie, 2005) although Mourant et al. (2007) found no gender differences in driving simulator sickness among a sample of older adults (aged 50–65). Graeber and Stanney (2002) have suggested that gender differences in simulator sickness and visually induced motion sickness may be accounted for by differences in susceptibility based on individuals' prior histories of experiencing motion sickness; when males and females were balanced for susceptibility, they found no difference in self-reported sickness between genders and no difference in study duration. Significantly higher levels of sickness were instead reported in the high-susceptibility group.

Health status is related to susceptibility to simulator sickness. Many researchers have suggested that individuals who are not in their usual state of fitness do not participate in simulator studies because they are at increased risk for SS (Johnson, 2005; Kennedy et al., 1993; Kolasinski, 1995; McCauley, 1984; Stoner et al., 2011). Specific health problems related to simulator sickness include head cold, influenza, upper respiratory illness, ear infection, ear blockage, and upset stomach (Kennedy et al., 1993). Fatigue, sleep loss, recent use of alcohol or drugs, and a history of

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