"New, Improved, Comprehensive, and Automated Driver's License Test and Vision Screening System"
by Sandy H. Straus, ESRA Consulting Corporation.
http://www.esracorp.com
Published May 2005, Arizona Department of Transportation

DRIVING SIMULATORS: YESTERDAY AND TODAY

From the Past to the Present

The driving simulators of today are products of research tools initiated in the early 20th century. These driving simulators, while largely employed in automotive industry, government, space, military, and academic research fields, in addition to the novice driver and recreational computer markets, among other fields, are also utilized in the medical sector for both research and patient recovery applications. In this chapter, we not only examine the history of driving simulators, but also consider these simulators as a possible testing mechanism in the driver's license bureaus.

Driving simulators were initially developed to assess the skills and competence of public transit operators in the early 1910s. Over the next four decades, mockup automobiles were equipped with devices to test drivers' responses to various stimuli. In some cases, mechanical moving scenes or filmed road scenes were shown. By the 1960s, a number of automobile manufacturers, automobile insurance companies, military agencies, universities, and aerospace companies used film approach simulators for studies involving a variety of visual displays (Decina, *et al.*, 1996). However, concerns about automobile safety and collision rates resulted in the development of driving simulator within the United States and overseas. Case *et al.* were among the first to study performance variables of older and younger drivers in 1970. By 1983, the Federal Highway Administration (FHWA), Human Factors Laboratory, Highway Driving Simulator (HYSIM) was developed as a fixed-base driving simulator, complete with an actual and highly equipped motor vehicle, to conduct a battery of studies ranging from hazard mitigation to human factors. The Swedish National Road and Transport Research Institute (VTI) Driving Simulator, fitted with a sophisticated motion system, and the Daimler-Benz (now DaimlerChrysler) Simulator, soon followed. In the Netherlands, driving simulations were successfully used to assess visual attention and analysis of drivers at about this time (Ponds *et al.*1988; Brouwer *et al.*, 1991). It was during the 1980s when the surge in popularity of video games and personal computers with improved imagery coincided with advanced interactive driving simulation. These led to complex yet even more realistic driving simulators, complete with imagery, traffic settings, automobile dynamics (e.g., braking or steering reactions), real-time features, and advanced mockup vehicles by the 1990s.

Charman (1997) cites a number of research studies that incorporate driving simulators and the significant correlation between these tools and on-road conditions. He also notes that the use of driving simulators for vision testing of drivers "…remains unproven". Clearly, no national or international driver's license bureau we surveyed in Australia, Canada, New Zealand, United Kingdom, and the United States implements driving simulators for driver's license vision testing purposes. Ideally, these are places where very large numbers of licensees could easily be studied. Nevertheless, a pilot study incorporating this technology, through ADOT, may serve as a prototype for this possible new and emerging vision testing area. These findings allow us to focus our attention on driving simulators and eliminate virtual reality, wearable forms of simulation, and military, truck, and flight simulators from our review. Some software programs seem to merit attention. However, since these do not quite have "the look and feel" of a motor vehicle, these types of simulation were eliminated from further review.

Saluäär, *et al.* (2000) devised a scheme of classification of simulators as low-level, mid-level, and high-level. Low-level simulators are associated with personal computers, pedals, and steering wheels. Mid-level simulators generally include a mockup automobile and projection screens linked with a personal computer for data collection and study. High-level simulators are more advanced and sophisticated simulators. They usually include or exceed the design of mid-level simulators and may have a Stewart platform or hexapod for support of movement and orientation of the mounted automobile.

The low-level simulators are among the most popular due to widespread use in driver education, medical establishments, rehabilitation settings, and academic projects. Some, low-level simulators, however, are associated with high costs due to size and proprietary features. The mid-level simulators are growing in popularity in government and academic environments due to their seemingly realistic simulations of the "driver experience," complete with sounds and visual images that are unrivaled in other types of experimental tests. High-level simulators require sophisticated hardware, software, and structural components. Due to the steep costs associated with these types of driving simulators, they are almost all exclusively available at universities, government agencies, and research centers at major automobile manufacturers. The National Advanced Driving Simulator (NADS) at the University of Iowa is an example of a high-level simulator.

Our Internet search yielded 59 different driving simulators from Australia (3 percent), Canada (2 percent), France (8 percent), Germany (14 percent), Japan (3 percent), Korea (2 percent), Netherlands (5 percent), New Zealand (2 percent), Norway (2 percent), South Africa (2 percent), Spain (3 percent), Sweden (3 percent), United Kingdom (7 percent), and United States (42 percent). (See Appendix C.) Only 2 percent of these simulators were not identified with any country or nation. We sought criteria specified in the ESRA DAT ™ and literature review. Approximately 81 percent of the driving simulators reviewed in this study were designed exclusively for research purposes. The remaining 19 percent were comprised of novice driver driving simulators, among other non-research applications.

A number of research driving simulators, particularly those within German and Korean universities and institutes, incorporate the Stewart Platform. This consists of a platform, one triangular face of an octahedron. The base, the opposing triangular face, connects to the platforms by six struts of the octahedron. These struts allow for positioning the platform in six degrees of freedom. Platform orientation and position vary. An actual motor vehicle is typically fitted with measuring devices, linked to a computer for data collection and analyses, and various road images are projected unto large screens within the dome-like structure. Stewart platforms allow for the simulation of low frequency accelerations. While valuable to traffic safety research efforts, the Stewart Platform cannot be placed in a driver's license bureau. However, such simulators can be used in carefully controlled experimental studies.

Interestingly, vision and motion measurements are typically hallmarks of high-level driving simulators, as opposed to the more mainstream mid-level driving simulators. NADS of the University of Iowa is a high-level simulator due to its numerous advanced features. Many of the driver education driving simulators are geared toward novice drivers whereas the rehabilitation and recovery driving simulators, in use at some hospitals and clinics, are geared toward ill or older drivers. This demonstrates the need for a driving simulator to bridge the gap between age groups and provide low-cost and effective vision and skill assessments. Many driving simulators now actually have "the look and feel" of motor vehicles because they may either be part of actual vehicles or offer a sophisticated combination of aerodynamic structural designs and graphic features.

Driving simulators are now used to assess the visual and physiological effects of fog on driving behavior. Fog reduces visibility and results in numerous motor vehicle collisions. Different densities of fog can be simulated to measure drivers' visual performance and speed. Studies show that driving speed increases as fog density increases because many drivers mistakenly feel as if they are slowing down (Snowden, Stimpson, and Ruddle, 1998). In addition, these simulators are better equipped to measure real-world driver performance and behavior than they ever were before. For example, some driving simulators offer ambient light and weather conditions. Other simulators, such as those created through Systems Technology Inc., also offer a strong record of peer-reviewed and independent studies of successful poor visibility and testing features of their STISIM driving simulators. The STISIM models, in widespread use in more than national and international academic and industrial settings, including various clients in Arizona, also offer simple self-customization features of different driving scenarios that allow driver's license bureau personnel the flexibility they require. Moreover, these driving simulators may also serve the dual purpose of screening at-risk drivers and providing an on-the-spot educational tool to the public on how they may exercise caution in order to drive safely on our nation's roads.

Furthermore, the amount of time for testing is also an issue of concern due to the long queues that are now common in many medical facilities and driver's license bureaus. Long periods of testing involving driving simulators, particularly those capable of providing comprehensive assessments, may also increase the likelihood of an examinee experiencing a flashback effect or other aftereffect associated with simulator sickness.

According to Johansson and Nordin (2002), a driver's field of vision require simulations of landscapes, roads, signage, vehicles, etc. on the visual screen of a driving simulator. Visual screens are dependent upon several factors, including acuity, display size, frame rate, resolution, and transport delay. The visual system is imperative to the driving simulator since it supplies visual information to the driver.

Research, Training, and Screening Usage

Driving simulators are usually designed for three purposes: Research, Training, and Screening. Such designs involve criteria that vary according to application.

Nearly every driving simulator in use today originated from research simulators within the military, government, academia, and automotive industries. Driving simulator research devices are generally utilized for empirical, investigative, and experimental usage. The majority of simulators today, as our study shows, appear to be utilized for research purposes.

Driving simulator training devices, however, are used for educational purposes. These are generally targeted toward novices and/ or secondary school students. Such simulators may be used on a daily, weekly, monthly, or yearly basis depending on the curricula developed by instructor(s) and/ or an agency. Driving simulator training models are educational tools used to gauge the performance of the student. Such devices may prove especially useful if our recommendation for accelerating the periods between driver's license issuance and renewal are accepted by legislation.

In the State of Florida, however, there are currently some proposals through the Florida Senate Transportation Committee (Long, 2005) for the possible use of driving simulators to test the skills of some traffic school students. (Traffic schools typically serve to promote safety, among other purposes, to motorists with traffic violation records.) These driving simulator devices may be used to improve student's performance through training but should not be deemed as a screening measure unless collision risk and record are safely and adequately documented and associated with such driving simulator usage. This has not been done to date by any entity worldwide. The distinctions between simulators need to be made because training devices cannot substitute for screening devices, or vice versa, unless there has been widespread independent testing and documentation to support such applications and nomenclature. Performance on simulators has not been directly correlated with on-road performance to date.

Furthermore, driving simulator screening devices are primarily used for detecting conditions or impairments that traditional tests cannot. Such devices are based on many years of published studies, results, and trials. For example, driving simulators are now used in research environments to detect or monitor dementia in drivers. Since the incidence of dementia is expected to jump 400% over the next twenty years (Whitmer, 2005), driving simulator screening devices may prove indispensable for transportation license screening purposes.

Driving simulators used for research, training, and screening purposes fill a niche that may otherwise not be available through conventional experimental and testing methods. Further studies must be conducted to enable usage for mass distribution. All driving simulators, irrespective of design, application, and frequency of usage, require safety and liability concerns to be addressed due to driving simulator sickness and other possible aftereffects.

SIMULATOR SICKNESS AND AFTEREFFECTS

What is simulator sickness?

Simulator sickness, or cybersickness, defines possible maladies associated with simulator usage. These include but are not limited to aviation, marine, military, and driving simulators. These feelings of nausea or discomfort occur in some subjects who use driving simulators. Simulator sickness may be triggered through vection, perceived motion, which occurs as a result of a disparity between visual and vestibular perceptual clues (Kennedy *et al.*, 1998). For this reason, vection is sometimes defined as a visually-induced deceptive body motion. While early studies relate primarily to military applications, the widespread use of simulators today allow for further investigations. Kennedy and Fowlkes (1992) characterize simulator sickness as "polysymptomatic", because several symptoms are at play, including blurred vision, cold sweating, concentration difficulty, confusion, drowsiness, eye strain, head fullness, nausea, pallor, and vomiting. Additional symptoms of cybersickness may include ataxia (postural disequilibrium or a lack of coordination), disorientation, dryness of mouth, fullness of stomach, headache, and vertigo (LaViola, Jr., 2000). Since there appear to be several rather than one single source of these symptoms, Kennedy and Fowlkes (1992) define simulator sickness as “polygenic”. Since there are so many factors that cause cybersickness, LaViola, Jr. (2000) reports that “….there is no foolproof method for eliminating the problem.”

Simulator sickness is sometimes classified as a form of motion sickness that may result from abrupt changes in movement or while the body’s orientation is relatively fixed yet exposed to moving visual scenes. Cybersickness differs from motion sickness in that visual stimulation, rather than vestibular stimulation, can trigger cybersickness.

Military studies laid the groundwork for modern simulator development and research activities. Crampton and Young (1953) associated motion sickness with video displays. Havron and Butler (1957) linked flight simulators with motion sickness-like symptoms. Miller and Goodson (1960) reported motion sickness in a helicopter.

There are three controversial theories that govern simulator sickness. These include the cue conflict theory, the poison theory, and the postural instability theory. The cue conflict theory arises from a sensory mismatch between what is expected versus what actually occurs in the simulator. The poison theory evolutionarily relates simulator sickness to the experience of poison or intoxication. The postural instability, unlike the sensory conflicts, defines the decreased ability to stabilize one’s postural motion. The interested reader is encouraged to explore Mollenhauer (2004) for characteristics of these theories, discussions of visual and vestibular systems, and simulator design factors that impact simulator sickness.

Aftereffects

Simulator sicknesses are often characterized by aftereffects. Stanney and Kennedy (1998) document significant and lasting aftereffects, particularly disorientation, elevated nausea levels and oculomotor disturbances following virtual environment exposure. Stanney, *et al.* (1998) warn of the hazards of disturbed locomotor and postural control following virtual environment exposure. They also cite perceptual-motor disturbances of concern. Recent studies show that three major aftereffects include postural equilibrium, fatigue and drowsiness associated with the Sopite Syndrome, and oculomotor changes such as eyestrain (Kennedy, *et al.,* 1997). Stanney *et al.* (1998) cite aftereffects that include disturbed vestibulo-ocular reflex (VOR) function, flashbacks, illusory climbing and perceived inversions of the visual field, increased risk of adverse adaptations to subsequent normal environments, postural disturbances, reduced complex psychomotor flexibility, and reduced motor control turning sensations. Kellog, *et al.* (1980), Kennedy *et al.* (1987) and Regan and Ramsey (1994) report aftereffects, such as the disorientation of subjects, for several hours after simulator usage. Gower and Fowlkes (1989) document aftereffects that persist for days.

Kolasinski (1996) suggest that the lingering effects of ataxic decrements, operational consequences of simulator sickness, among other delayed aftereffects, triggered through use of virtual reality systems, are of special concern.

Flashback Effects

Flashback effects may result from simulator exposure. These effects may be characterized by flash images or flashbacks that appear, following driving simulator usage. Lackner and DiZion (2003) describe this phenomenon, characteristic of flight simulator exposure, as a consequence of the adaptation process. Head and body movements are associated with "….unusual and inappropriate patterns of sensory feedback." Several studies underscore the susceptibility of some simulator users to flashback effects, as a type of aftereffect that may not be immediately obvious until hours or days after a simulator session. Kolasinski (1996) refers to this phenomenon as delayed flashbacks.

Baltzley *et al.* (1989) report that some cases of ataxia and unsteadiness persist for more than 6 hours and, even longer than 12 hours. Flashback effects are a potentially greater risk to driving simulator users because these effects last longer. Baltzley *et al.* (1997) note the unique incidences of flashback effects and coping mechanisms developed by the pilots themselves that tend to mask the extent of post simulator effects. Hence, flashbacks pose a safety risk through navigation activities (Kennedy *et al.*, 1992).

Past studies document significant health and safety concerns associated virtual environments due to visual flashbacks, disorientation, and disequilibrium that occur up to 12 hours after a simulator session (Kennedy *et al.*, 1995). However, a lack of flashback studies, as these relate to driving simulator usage among all age groups, disallows quantification of such aftereffects. For these reasons, further studies are needed and conservative approaches, what we call "flashback effect management", are required.

Cyberadaptation Syndrome and Simulator Adaptation Syndrome

The transition between the virtual environment and the real environment is filled with different responses to different simulator users. This transition may be accompanied by varying degrees of simulator sickness. According to Lackner and DiZio (2003), virtual environments and the aftereffects that occur on the return to the normal environment are characterized by "full set of behavioral, psychological and physiological changes." Cyberadaptation Syndrome, or Simulator Adaptation Syndrome, may describe this journey and its characteristics.

Stanney and Salvendy (1998) report that Simulator Adaptation Syndrome (SAS) underscores the need for standard measurement approaches and sensorimotor discordance identification that trigger this reaction to driving simulators. Simulator Adaptation Syndrome (SAS) creates autonomic symptoms, such as nausea, in some drivers of driving simulators. According to Rizzo *et al.* (2003), these may be due to a broad range of simulator displays, devices, technologies, and scenarios- all that may present a drawback to testing if not properly monitored and reviewed.

Factors of Simulator Sickness

Kolasinski (1996) cite several factors associated with simulator sickness, including age, degree of control, duration of task, field of view, gender, and lag. Kennedy *et al.* (1997) identify the following five classes of determiners of simulator sickness as equipment and technical system factors; user characteristics, duration of time in the simulator; simulator usage schedule and kinematics. LaViola, Jr. (2000) cites display and technology issues, position tracking error, lag, and flicker as several contributing factors to cybersickness in virtual environments. Some individual factors, as discussed, include age, gender, illness, and position in the simulator. The time between the subject beginning an action and the action occurring in the virtual environment defines lag. According to Pausch *et al.* (1992) delays in lag can result in cybersickness. Nevertheless, proper control of imagery, movement, field of view, and timing, among other factors, of driving simulator sessions may reduce the likelihood of simulator sickness.

Simulator Sickness Studies

Baltzley *et al.* (1989) report that from 6 to 62 percent of military pilots experience simulator sickness. Regan and Price (1994) and Cobb *et al.* (1998) identify simulator sickness symptoms of eyestrain, headache, nausea, and malaise after 10 –20 minutes of virtual reality exposure in non-pilots. Kennedy *et al.* (1995) reveal that 30percent to 50 percent of 2,000 flight simulator testees experienced simulator sickness, such as Sopite Syndromr, characterized by fatigue or drowsiness, following a simulator session. They conclude that there exist major safety implications, particularly for elderly persons, who may be exposed to driving simulators. Although rates are dependent on the type of simulator, Gillingham and Previc (1996) document simulator sickness in 40 percent to 70 percent of pilot trainees following use of high-quality military flight simulators. Kennedy *et al.* (1997) cite reports of simulator discomfort from United State Navy pilots and the United States Air Force where simulator sickness could be detected in almost all simulators. Baltzley *et al.* (1997) note that simulator studies of United States Coast Guards in training over several weeks led to the conclusion that unsteadiness and postural disequilibrium are the post effects that prompt the greatest safety concerns. Stanney *et al.* (1998) cite several studies where 80 percent to 95 percent of participants in a number of virtual environment studies reported adverse symptoms, and 5 percent to 30 percent experienced symptoms severe enough to end participation. Kennedy *et al.* (2001) estimate, on the basis of a large sample study, that 10 to 20 percent or more testees will exit a simulator session after a few minutes due to simulator sickness.

The Simulator Sickness Questionnaire

In 1965, Kennedy and Graybiel (1965) developed a motion sickness questionnaire that, following several modifications, formed the foundation for today's simulator sickness questionnaires.

The Simulator Sickness Questionnaire (SSQ) quantifies simulator sickness and divides the symptoms according to disorientation, nausea, and oculomotor discomfort (Kennedy, *et al.*, 1993). It allows for the monitoring of simulator performance with data from a computerized SSQ. The questionnaire provides a more valid index of overall simulator sickness that distinguishes it from motion sickness. The SSQ more accurately identifies the basis of simulator sickness.

Stanney *et al.* (1998) report that, while this questionnaire was originally designed as an assessment tool for aircraft simulator system subjects, it allows subjective symptomatology assessments and scores on simulator sickness subscales. SSQ scoring is based on factor analytic models (Kennedy *et al.,* 1992).

Field of View and Flicker

Conflicting findings suggest that wide field of view may not greatly impact the susceptibility of cybersickness. Although Lestienne *et al.* (1977) report intense sensations of motion sickness with a wide field of view, Anderson and Braunstein (1985) document similar findings with a reduced field of view. Although the intensity of simulator sickness may be independent of screen size or number of screens of a driving simulator, Hettinger and Riccio (1992) associate vection with wide field of view displays.

Allen *et al.* (2003) conducted a pilot study of novice drivers using different driving simulator system configurations, including a single monitor desktop, three-monitor "wide field of view" desktop, and a cab with a wide field of view projection. Their objective was to show that a personal computer-based driving simulator system could be used in both research and non-research settings. Approximately 91.7 percent of the participants did not report any discomfort. Single monitor displays demonstrated the highest number of surpassable speed limits. The lowest number of surpassable speed limits, on average, were shown by Wide Field of View Desk Top, composed of three computer monitors. Approximately 2.8 percent indicated that the simulator systems made they feel queasy. These symptoms did not appear to be influenced by increasing display field of view.

Jeng-Weei *et al.* (2002) reports that the rate of nausea decreases when many clouds are used as an independent visual background. This may be due to the naturalness and stableness associated with clouds.

Edwards *et al.* (2003) associate large field of view, e.g., 150 degrees, with simulator sickness. Therefore, field of view, speed settings, and time duration of the driving simulator test may limit simulator sickness. Johansson and Nordin (2002) demonstrate that a lack of synchronization between the visual and motion systems also contributes to simulator sickness (Johansson and Nordin, 2002).

Sparto *et al.* (2004) report that wide field of view devices result in greater simulator sickness. They urge safety testing prior to any use in a clinical setting. However, they show that 69 percent of subjects did not experience simulator sickness symptoms when a wide field of view environment was used to gauge self-reported tolerance to movements. They theorize that reduced exposure time, display device type, content and nature of task, and significant rest breaks between trials may all influence susceptibility to simulator sickness.

Kennedy *et al.* (1988) link vection with increasing retinal periphery stimulation. McCauley and Sharkey (1992) relate driving simulation motion and stimuli to vection. LaViola, Jr. (2000) notes that the complexities of the visual system account for many more vection-related physiological factors. These may be evident during driving simulation when the optical flow patterns of traffic, structures, and roads travel past the examinee's periphery. Wider field of views may also increase the susceptibility to flicker, which can cause eyestrain and other cybersickness symptoms.

There appears to a tradeoff associated with 1-screen and 3-screen simulators. While the 3-screen models may provide more realistic views, they may also consume more space and induce more cases of simulator sickness among subjects.

In order to reduce simulator sickness and improve task performance, there are effective image resolution requirements in aviation training simulators at the Federal Aviation Administration (Mollenhauer, 2004). It is unclear now, based on our literature review, whether there are such requirements exist in any government agencies as these relate to driving simulators due the various applications.

Gender

In several studies, females are more likely than males to report higher simulator sickness ratings (Reason and Brand, 1975; Kennedy *et al.,* 1995; Rinalducci *et al.*, 2002; Allen *et al.*, 2003; Edwards *et al.*, 2003; Rizzo *et al.,* 2003). This finding may also relate to the size of the field of view, which may be larger among females.

Incidence of simulator sickness

The incidence of simulator sickness varies from application to application. In driving performance studies, Rinalducci *et al.* (2002) shortened driving simulator tests to prevent simulator sickness. However, approximately ten percent of participants from three different age groups reported simulator sickness and were unable to continue testing. Lee *et al.* (2003) determined that approximately 9 percent of the participants in their study experienced "simulator sickness," although a very short and mild degree of dizziness after completing the driving simulator session. Yet, this did not affect their performance. According to Edwards *et al.* (2003), simulator sickness prevented forty percent of recruited older participants from completing their study. They indicated that some participants complained about disorientation, dizziness, and nausea, while others were observed in bouts of sweat and paleness that led to increased head movement, repeated swallowing, and vomiting.

Impacts of Cybersickness

There appears to be a lack of research on cybersickness and the impacts of freedom of movement or control necessary to "….minimize the adverse effects of human-virtual environment interaction" (Stanney *et al.*, 1998). Little or no control over simulator movements may account for the susceptibility of crewmembers and pilots to sickness (Reason and Diaz, 1971; Casali and Wierwille, 1986). Although user-initiated control may impact symptoms of simulator sickness (Stanney and Hash, 1998), Rizzo *et al.* (2003) investigate whether driver SAS initiate poor control of a simulator vehicle or if vehicle control is weakened by SAS.

Studies of At-Risk Drivers

Rizzo *et al.* (2003) evaluated the effects of SAS on driver performance of at-risk older drivers, including patients who were diagnosed with Alzheimer's disease and stroke. Feelings of discomfort accounted for an early simulator drop out rate of 21 percent of the 164 drivers. Body temperature increase, dizziness, light-headedness, nausea, and nervousness were correlated with high levels of discomfort scores through questionnaires provided to drivers immediately after driving simulator usage. These findings were in good agreement with earlier studies by Kennedy *et al.* (2001). Furthermore, Kolasinski (1996) suggests identification, training, and warnings as methods to reduce simulator sickness in at-risk users.

Simulator Sickness Mitigation Strategies

Mitigation strategies vary among simulator users. Some try conventional approaches while others incorporate various devices.

LaViola Jr. (2000) suggests sitting, rather than standing, in a virtual environment may decrease cybersickness symptoms because it would diminish postural control. He further describes ways to reduce cybersickness, including the use of motion platforms, direct vestibular stimulation, rest frame usage, and an adaptation program. However, there appears to be a tradeoff with the adaptation program, which, while helpful in the virtual environment, seem to increase the likelihood of aftereffects and flashbacks due to an increase in exposure time, among other factors.

Mollenhauer and Romano (2002) incorporate the application of the ReliefBand®, as a simulator sickness mitigation device. Patients who experience nausea from pregnancy, chemotherapy, and motion sickness sometimes use the ReliefBand to impart a mild electrical stimulation to combat nausea. According to the ReliefBand website (2005), the ReliefBand Device should always be used under medical supervision. There are also risks to pacemaker users who may experience interference through use of the device.

Clearly, use of ReliefBand, and/ or any device that imparts electrical simulations, introduces a whole new set of possible liability issues, especially for transportation licensing agencies, among others, due to the possible side effects to different people.

Future Simulator Sickness Studies

While military studies have contributed to simulator sickness studies for more than five decades, the popularity of driving simulators today, in educational, research, and public distribution, merits further review and studies. According to Kolasinski(1996), "….longer-lasting effects, especially those such as flashbacks and ataxia, pose a safety risk to both users of simulators and to others… It is important that ataxia, as well as sickness, be investigated because…. of the many possible liability issues surrounding widespread use of such systems." She states that such sicknesses threaten the use and application of driving simulator products due to liability concerns.

A lot of the available literature relates directly to the novice, particularly, aviation trainees. These studies generally, fail to target older simulator users and those at-risk. Such users may have special needs and reactions that need to be addressed. There is, therefore, a need for further studies on the flashback effect, especially as these relate to older and at-risk drivers, among others. Kennedy *et al*. (1995) suggest that for future research, simulator exposure time should be carefully recorded in order to assess its impact on aftereffects. Stanney *et al.* (1998) also recommend studies of "….delayed effects from virtual experiences…. in order to ensure the safety of users once interaction with a virtual world concludes."

According to Kennedy *et al.* (1997), "Formal information exchange programs should be instituted to not only aid industry in reducing product liability punitive awards, but it is in the best interest of the public."

At the Seventh International Conference on Human Computer Interaction in 1998, a special committee underscored the importance of measurement approaches, standardization, and identification of sensorimotor discordances of aftereffects. Many national and international organizations continue to meet to review and discuss simulator safety mechanisms, among other driving simulator issues.

SAFETY RECOMMENDATIONS

While driving simulators appear to offer a cost-effective alternative to screening all drivers, there are liability issues that every agency needs to consider prior to implementation, application, or use of driving simulators for transportation license testing purposes.

Kennedy (1995) proposes certification tests to avoid the accidents that can result from simulator aftereffects, especially when driving, flying, or roof repair. He warns "… simulator operators, developers, and manufacturers could be liable" since "an individual may be injured as a result of simulator exposure". According to Kennedy *et al.* (1997), there now exists, from virtual environments to real-world settings, "the transfer of maladaptive cognitive and/or psychomotor performance…. with, as yet, unknown adverse legal, economic, individual, and social consequences." Kolasinski and Gilson (1998) conclude that simulator sicknesses and aftereffects "….pose severe safety risks and raise serious liability issues." Surveys of ten simulators at six different Naval and Marine Corps site yield that simulator sickness, especially within flight simulators, occurs "…during maneuvers that do not occasion them…." Hence, Kennedy *et al.* (1989) recommend monitored and restricted activities, such as driving, immediately after simulator sessions due to safety concerns.

Similarly, Stanney *et al.* (1998) recommend that following simulator sessions, "….bans on driving, roof repair, or other machinery use…. may be necessary." They warn that the subjects who feel less affected or ill when they exit such simulator sessions may, in fact, be at greatest risk of simulator sickness and/ or its aftereffects, as documented by Kennedy *et al.* (1995). Such concerns led to grounding policies at the Navy and Marine Corps after simulator flights (Kennedy *et al.*, 1989, LaViola, Jr., 2000).

Stanney *et al.* (1998) further note "Of equal importance is ensuring the health and welfare of users who interact with these environments….If the human element in these systems is ignored or minimized, it could result in discomfort, harm, or even injury. It is essential that VE developers ensure that advances in VE technology do not come at the expense of human wellbeing." They also warn of the negative social implications and impacts resulting from the user's misuse of the virtual environment (VE) technology.

It is very likely that a little simulator sickness discomfort may be a small price to pay to weed out at-risk drivers. These drivers pose a risk to themselves as well as to other motorists. However, driver safety and health cannot be compromised at the expense of driving simulator usage. As long as driving simulators are integrated in the driver's license testing process, as we propose, then the comfort and safety of all subjects must be ensured.

Although driving simulator usage poses a safety concern, we suggest that transportation agencies and medical facilities have examinees sign waivers, indemnification, and release of liability waivers and not drive, fly, and/ or perform roof repair, and/ or operate any machinery until at least 72 hours have elapsed following a simulator test session to reduce the possibility of potential liability for any possible aftereffects, flashbacks, and/ or simulator sicknesses that some subjects may experience. We also urge these agencies to implement driving simulators with long histories of success, implementation, safety testing, and usage as these relate to both novice *and* older drivers. These should be documented through numerous independent and peer-reviewed publications over the last ten years in several different subject areas. Although many factors may account for simulator sickness and its aftereffects, age appears to be among these aspects. As age increases, susceptibility of motion sickness rapidly rises (Gahlinger, 1999). Hence older drivers may be more susceptible to simulator sicknesses and discomfort. Older drivers may have special needs that not all driving simulators provide. Transportation may need to be arranged for driving simulator testees. A panel of independent scientists and physicians should work closely with these agencies to monitor such progress and performance.

We strongly recommend that transportation agencies and medical facilities have examinees sign waivers, indemnification, and release of liability waivers and not drive, fly, and/ or perform roof repair, and/ or operate any machinery following all other automated forms of testing. Since these may not incorporate simulation, and the effects, if any, may be very short, a team of independent physicians and scientists should determine the appropriate amount of time to refrain from such activities.

Ideally, a pilot test phase should be implemented to determine the feasibility of driving simulator usage for any transportation license testing purposes.

RECENT AND CURRENT DRIVING SIMULATOR RESEARCH

Increases in both driving simulator and on-road driving collisions have been linked to peripheral vision weaknesses (Keltner and Johnson, 1992; Szlyk *et al.*, 1992; Szlyk *et al.*, 1993). Several studies document use and application of driving simulators as a viable option for driver safety analyses. Some studies focus exclusively on dementia drivers. Lundberg (2003) divides these dementia driving studies into two categories: those that relate to collision involvement or driving difficulty and those that are geared toward driving performance predictability.

Szlyk *et al*. (1993) used driving simulators to assess driver safety in visually impaired and non-impaired drivers with juvenile macular dystrophies. Szlyk *et al.* (1995) used an interactive driving simulator to measure compromised vision and visual field loss of drivers of all ages and visual conditions. They successfully identified weaker driving skills, increased eye movements, and slower simulator driving speeds in drivers age 50 to 83 years than the drivers age 19 to 49 years, through an 8-minute driving simulator session. They also associated collision risk with compromised vision and visual field loss. Several subjects were diagnosed with AMD, hemianopsia (when one or both eyes are characterized by blindness in one half of the visual field), among other disorders and diseases.

Decina *et al.* (1996) conducted a useful study of existing simulators for improving the safety training of novice drivers, primarily younger drivers. They determined that high costs and limited accessibility of driving simulators were a deterrent for novice training applications. Although they found that the majority of driving simulators were employed for research and training purposes, Decina *et al.* (1996) suggested a type of network setup "…enabling simulators in remote locations to share scenarios, instructions, and scoring…"

Rizzo *et al*. (1997) utilized the Iowa driving simulator to observe strong predictors of collision in drivers with Alzheimer's disease (AD) and drivers without dementia. Visual and cognitive test scores were used to determine collision susceptibility in drivers with mild dementia. No visual acuity differences, apart from a slight reduction in static spatial contrast sensitivity were observed in the drivers with AD. Yet, several poor neuropsychological measures were apparent in the mild to moderate dementia group of AD drivers. Approximately 29 percent of the AD drivers engaged in the driving simulator study experienced collisions. These findings, among others, led Rizzo *et al.* to support the idea that some AD drivers with mild dementia "….remain fit drivers and should be allowed to continue to drive." According to Rizzo *et al*. (1997), simulated collision avoidance scenarios "….provide demonstrations of driver behavior that cannot be obtained any other way. The simulator record can be compared to that of the black box flight recorder from a downed aircraft, yet no one is injured." Owsley *et al*. (1998) associated collision risk and poor performance in a driving simulator with significant binocular visual field loss.

The University of Michigan Transportation Research Institute driving simulator consists of a mockup of a car based on network of Macintosh computers and, among other things, a 33 degree horizontal and 23 degree vertical field of view. In an effort to assess the visual demand of drivers in three age groups (18 to 24 years, 35 to 54 years, and 58 to 68 years), Tsimhoni and Green (1999) illustrate that the radius of curvature creates a higher visual demand, the proportion of time a road is visible, among the driver cohorts ages 58 to 68 years.

Westlake (2000) supports the use of driving simulator assessments and advanced vision tests, among other approaches to effectively predict collision involvement through these types of cognitive and perceptual tests. Szlyk *et al*. (2002) promotes the use of driving simulators as screening tools for dementia drivers. Szlyk *et al*. indicates that driving simulators also allow the potential to identify neuropsychological tests that provide driving performance predictability. Ball (2003) cites driving simulator performance studies that are associated with useful field of view. Lee *et al*. (2003) encourage the use of driving simulations as an initial screening tool for at-risk drivers through their successful study to assess the driving performance of drivers ages 60 to 88 years. They show that the simulated driving assessment results were in good agreement with the on-road assessment results. These assessments identify decrements associated with cognition, and medical, peripheral vision, and sensory conditions. Hence such tests may also be used to study the driving performance of patients with AD. Ball and Owsley (2003) and Duchek *et al*. (2003) support evaluation and more frequent reevaluation of drivers with mild and very mild stages of dementia of the Alzheimer type.

In the Netherlands, driving simulators, specifically, the mockup of a car positioned before a 165-degree by 45-degree projection screen, continue to proved effectiveness in evaluation of the impacts of visual field defects on the driving performance of driver cohorts ages 37 to 86 years (Coeckelbergh *et al.*, 2002). An experienced driving examiner from the Dutch Driver's License Authority (Centraal Bureau Rijvaardigheidsbewijzen, or CBR) verifies these results through a standard road test for drivers who do not satisfy the vision requirements for driving.

At the University of Iowa Hospitals and Clinics, the Simulator for Interdisciplinary Research in Ergonomics and Neuroscience (SIREN) was set up to assess at-risk drivers through a mockup of a car equipped with a 150-degree forward view and a 50-degree rear view. Studies targeted patients with AD, drowsiness, old age, Parkinson’s disease, sleep apnea, or traumatic brain injury (Rizzo, 2002). SIREN varied elevation, roadway type, roadway surface conditions, signal control, and visual environment to optimally test driver performance.

Currently, two major studies, among many worldwide involving driving simulators, are underway at the University of Iowa and Harvard University. At NADS at the University of Iowa, researchers seek to validate a vision test for simulated driving performance tests (Galluzzo, 2004). However, this study is limited to contrast sensitivity testing. At the Schepens Eye Research Institute at Harvard Medical School, research is now in progress to study driving in visually impaired patients using driving simulators. Dr. Eli Peli and his team of researchers are building specific scenarios using a simulator from FAAC Incorporated of Ann Arbor, Michigan. After more than 3.5 years of various phases of development, data collection is planned for July 2004. According to Dr. Peli, the FAAC simulator "…appears to provide abilities to create scenarios and really analyze data" (Peli, 2004). Although the basic driving simulator tool is in use for driver training programs at several different government agencies (FAAC Incorporated, 2004), at this stage, it does not seem to be marketable for or applicable to driver's license vision testing. Meanwhile, some clinics in Florida already use DriveAble®, a driving simulation used to measure on-road driving skills, and medical and cognitive weaknesses (Florida At-Risk Driving Council, 2004; Jenks, 2004).

Presently, a study is in progress at the National Advanced Driving Simulator (NADS) at the University of Iowa in an effort to validate a vision test for simulated driving performance tests (Galluzzo, 2004). However, this study is limited to contrast sensitivity testing. At the University of Queensland in Australia, touch screens are being developed to detect older motorists who are suffering from the early signs of Alzheimer's. These two-hour tests, including road simulation, are planned for full-scale implementation in General Practitioner surgeries and health centers within three years (Atkinson, 2004).

Drive Safety, Inc. of Utah develops a number of driving simulators for national and international usage, especially in the research and development areas. They also perform safety tests of other driving simulator products. While Drive Safety, Inc. publishes their list of driving simulator users in the private and public sector, they do not disclose the names of the companies whose driving simulator products they test. According to private communication with Drive Safety, Inc. (2004), there are substantial fidelity concerns that their team of scientists and psychologists identify.

Furthermore, Hopkin *et al*. (2004) support driving simulators, among other assessment techniques, in order to research and implement adequate screening mechanisms for dementia drivers and other at-risk drivers in Ontario, Canada, and elsewhere. They cite studies that show dementia drivers are two to five times more susceptible to collision involvement.

Ideally, the driving simulator could be used to supplement current vision testing assessments of at-risk or high-risk drivers to screen those who require further medical evaluations. Since driving simulators have contributed to safety improvements on our roads and in our automobiles, they can and should be considered for use in driver's license testing practices. Also, Roenker *et al*. (2003) discuss administration and scoring anomalies in road tests that are less prevalent in driving simulators due to computerization.

Following a thorough review of many interesting driving simulator products, as tabulated in Table 100 of Appendix T, we identified the best simulators on the basis of results of a questionnaire ESRA developed. Although respondents requested confidentiality of their questionnaire responses, these questions included but were not limited to the following on their driving simulator product(s):

- Complete references and contact information
- Safety testing such as flashback effect studies
- Identification of any special features or unique functions
- Complete bibliographic information of any published or peer-reviewed studies on any driving simulator products.
- Amount of time required to complete tests.
- Instant scoring mechanisms.
- Network capabilities.
- Bilingual capabilities.
- Full automation.
- Cost of each unit, customization, warranties, training, shipping, etc.
- Discounts.
- Availability and Applicability.

Following a questionnaire developed by ESRA, and, as tabulated in Table 100 of Appendix T, an extensive review of national and international driving simulators, we identify the following three simulators for implementation in the ESRA DVAT™ System (Figure 7):

RECOMMENDED DRIVING SIMULATORS

Table 4: Models and Special Features of Driving Simulators

Model and Special Features
Systems Technology, Inc. STISIM Drive ™ Model E-01 Driving Simulator (1-screen with cab) STISIM Drive ™ Model E-02 Driving Simulator (1-screen desktop) STISIM Drive ™ Model E-03 Driving Simulator (3-screen with cab) STISIM Drive ™ Model E-04 Driving Simulator (3-screen desktop) • numerous self-customization driving scenarios. • 1 or 3 screen display models. • driver behavior tests. • Networking capabilities. • PC Windows capabilities. • ideal for vision status tests as part of the ESRA DAVT™ and ESRA VAPT™. • ambient and simulated light and weather conditions. • simulation similar to visibility and contrast reduction due to fog, rain, and snow. • based on very strong record of publication (more than 50 peer-review studies). • Recent peer-reviewed and published studies on older drivers include : Bolstad, 2000; Bolstad, 2001; Freund, *et al.,*2002; Hassanein *et al.,*2003,; Lee, 2002; Lee *et al.*, 2003. • international applications. • associated with STISIM users and applications at more than 66 national and international universities and medical institutions, 33 companies, and 13 U.S., foreign, and state agencies. • clients include Arizona Department of Public Safety and the Tucson Police Department.

While we initially considered Raydon Corporation Virtual Driver™ driving simulator products to appear very promising, we were unable to recommend any of their products at this time due to the following reasons: In February 2005, information on pricing, economies, warranties, safety and performance records, published studies, and references, among other liability concerns was unavailable. There was also no indication that any of the Raydon Corporation products were independently and extensively tested on older drivers and/ or at-risk drivers. Raydon Corporation declined to provide any documenttation of this information. We therefore have concerns about the safety and performance record of the Raydon Corporation driving simulator (Virtual Driver™) products at this time.

Raydon Corporation also would not disclose the networking capabilities of its products and therefore it is unclear as to whether or not their products have automation and networking capabilities. Such features are essential to automated testing and, as demonstrated in this report, the cost-effectiveness of new driver's license testing systems and applications.

Through nearly one century of usage, driving simulators, in the automotive industry, government, law enforcement, space, military, medical, academic research fields, and driver education programs contribute to quality improvements of safety on our roads, in our military operations, and through our patient recovery processes. On the bases of these applications, as well as recent studies we highlight, the addition of a driving simulator, as a possible screening device of a comprehensive vision testing system, merits further consideration. Driving simulators appear to optimize the ability to test driver response to common road, lighting, weather, and pavement hazards without the risk of collision, fatality, or injury of driver, passenger, or driver's license bureau personnel. Ideally, a three-screen driving simulator could be used to supplement current vision testing assessments of at-risk or high-risk drivers to optimally screen the vision of those who require further medical evaluations, in particular, dementia drivers and others with neurological disorders. Since driving simulators have contributed to safety improvements on our roads and in our automobiles, they can and should be considered for use in driver's license testing practices once the safety and liability issues are adequately addressed. At a time when gas prices are on the increase, and driver's license bureau staffing and motor vehicle maintenance costs prevail, driving simulators may prove as cost-effective and "environmentally friendly" supplements to traditional driver's license vision tests once all associated safety concerns are addressed. The ESRA DVAT™, though two automated tests (to test vision condition and function) and one driving simulator (to assess eye status and strategy) constitute a system that covers the most comprehensive measures of visual acuity, condition, function, performance, and status measurements that we know of for any transportation licensing agency, including the driver's license bureau setting.