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Evaluating driver performance on the road and in a simulator

Erik C. B Olsen
San Jose State University

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EVALUATING DRIVER PERFORMANCE
ON THE ROAD AND IN A SIMULATOR

A Thesis
Presented to
the Faculty of the
Human Factors/Ergonomics Program
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By
Erik C. B. Olsen
August 1996

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APPROVED FOR THE HUMAN FACTORS/ERGONOMICS PROGRAM

Anthony D. Andre, Human Factors/Ergonomics, Chair

Louis E. Freund, Industrial & Systems Engineering, Member

Kevin Jordan, Psychology, Member

Del Coates, Art & Design, Member

APPROVED FOR THE UNIVERSITY

ABSTRACT

EVALUATING DRIVER PERFORMANCE ON THE ROAD AND IN A SIMULATOR

By Erik C. B. Olsen

The purpose of this study was to determine if a driving simulator can replace an on-road evaluation in the context of an Occupational Therapist (OT) Driver Assessment and to identify the differences between road and simulator environments. The benefits of using a simulator to perform driver assessment are many-fold and include: 1) a more time- and cost-efficient method for evaluations 2) the ability to evaluate drivers under complex conditions and 3) the improvement of driver safety.

With this in mind, the present study focused on differences between environments and compared driver evaluations conducted on-road to those conducted in a medium-fidelity driving simulator. Overall, the data shows that some parts of the driver evaluation process may be better performed in a simulator. Continued research is proposed, addressing the differences between actual and simulated vehicle environments and the establishment of OT evaluation techniques in conjunction with simulation.

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This is dedicated to the memory of my Grandfather, Charles Witt Telford, Ph.D., a former faculty member and Chairman of the Psychology Department of The San Jose State University.

The matter of the external work is everywhere in a perpetual state of violent motion. It is as much so on the seemingly slumberous surface of a lake as in the storm-dashed foam of the ocean (Telford, 1968).

Table of Contents

Acknowledgments	v
List of Tables	vii
List of Figures	viii
Introduction	1
Method	18
Results	34
Discussion	51
Conclusion	60
References	63
Appendices	71-98
Appendix A. Review of Study Instructions	71
Appendix B. Driving Questionnaire	72
Appendix C. Cognitive Failures Questionnaire	75
Appendix D. Driving Results Form	78
Appendix E. Simulator Orienting Exercise Instructions	81
Appendix F. Simulator Instructions	86
Appendix G. On-Road Instructions	91
Appendix H. Additional Participant Information	95
Appendix I. Interview Questions	97

List of Tables

TABLE	PAGE
1. Tests Used to Collect Data on Abilities Related to Driving Skill	19
2. Common Aspects Between the 2 Environments	24
3. Variable Abbreviations	35
4. Pearson's R Correlation Matrix	38-40
5. Descriptive Statistics	44

List of Figures

FIGURE	PAGE
1. Time Warner 5-Screen Simulator	22
2. Test Administration, Scoring and Set-up for Simulated Drive	29
3. Experimental Room Set-up and Simulator - Top view	30
4. On-Road Route Map	31
5. Simulator Route	32
6. Uneasiness of Participants	36
7. Overall Road Score X Overall Simulator Score	41
8. Main Effect of Environment on Overall Performance Score	43
9. Age X Road Score	45
10. Regressing Age, Accidents, CFQ, RT, and Tickets on Overall Score	46
11. Road X Simulator Scores for Steering	48
12. Main Effect of Environment on Steering Performance Score	49
13. Main Effect of Environment on Brake Performance Score	50
14. Main Effect of Age on Additional Skills Performance Score	52

Evaluating Driver Performance on the Road and in a Simulator

An increased need for improved driver safety has existed since the first motor vehicle fatality was reported over 96 years ago. That was September 13, 1899, in New York, NY, when Henry H. Bliss was struck by an automobile (Gunby, 1992a). In 1994 the U. S. had over 175 million licensed drivers and, according to U.S. Department of Transportation (1995), there were over 3.2 million injuries and over 40,000 fatalities attributed to driving accidents. With this growing number of drivers and the on-going problem of traffic safety, various campaigns, programs, and driving laws have been created and implemented over the years aimed at making our traffic system safer.

Slogans such as "buckle up" and "friends don't let friends drive drunk" have been created in hopes of curtailing these staggering driving statistics. Further, new driving laws have been implemented such as the mandatory seat belt use law. Another example includes Maryland's "zero tolerance" law that makes it illegal for drivers under age 21 to operate a motor vehicle at a blood alcohol level (BAC) of 0.02% or higher (Gebers, Romanowicz, & McKenzie, 1993). Other promising steps include graduated licensing programs for novice drivers, which gradually and systematically lift licensing restrictions, and has shown significant reductions in accidents in New Zealand and Australia (Gebers et al., 1993). Other accident countermeasures include raising the licensing age, implementing driving curfews, increased driver training, graded licensing, and license extension by mail for clean-record drivers.

Fortunately, the overall effect of such programs seems to be positive. Significant reductions in accidents over the past decades have been reported by the National Highway Traffic Safety Administration (Gebers et al., 1993). For

example, the percent of alcohol-related fatalities declined from 57 percent in 1982 to 41 percent in 1994. The motor vehicle fatality rate per 100 million vehicle miles traveled has steadily declined from 5.5 in 1966 to 1.7 in 1994 (U.S. Department of Transportation, 1995).

The success and growth of such programs and campaigns is an example of the concern our nation maintains for traffic safety. Alternatives for improving driving safety are still needed, as the population of the United States rapidly approaches the 300 million mark and our nation's people continue to rely on the automobile for transportation. Since that first fatality in 1899, the U.S. traffic death toll has reached nearly 2.8 million people (Gunby, 1992a). In 1990, almost 6.5 million motor vehicle crashes were reported—about one every 5 seconds (Marwick, 1992). More than just campaigns and frightening statistics, alternatives for driver education, training, evaluation, and licensing are continually needed.

Standard Licensing Process

The typical licensing process begins with drivers' education and training, followed by on-road instruction and examination. Driver's education consists of classroom instruction, where one learns the rules of the road and receives education about driving safely. Such education is taught in high school as required by law (Department of Motor Vehicles, 1995) or by independent driving instructors through a driving school certified to do so in that state. While various methods have been used to teach driving education (e.g., books, films, discussion groups, quizzes), eventually, on-road training and evaluation is administered in preparation for the driver's licensing examination, using an actual vehicle. On-road driving performance evaluation involves scoring or otherwise measuring performance of the driver to judge his or her ability to drive safely. Such

evaluations are made daily by driver educators and parents of new drivers, by department of motor vehicles staff and evaluators, throughout the research community for a variety of applications, and as part of established driving evaluation programs.

Road Evaluation for Testing

Using an automobile on the road continues to be the "gold standard" of instruction and evaluation for driving. The driver licensing examination is usually performed at the state's Department of Motor Vehicles (DMV). The licensing process often includes a knowledge test, some sort of visual acuity or perception examination, in addition to the on-road evaluation. Road evaluations are administered by DMV driver's examiners and are considered important for measuring driving performance. Indeed, in 1990, the California DMV initiated a program to increase the level of driving competency of drivers (Hagge, 1994). "A key element of this program involves the development and implementation of an improved drive test," states the introduction of this report.

Road Evaluation for Research

The research community also uses the on-road evaluation to measure driver performance. In fact, such research has contributed to improved road safety, highway and vehicle design, and driver evaluation techniques (Waller, 1991), as suggested by the falling per-mile loss rates (U.S. Department of Transportation, 1995). Specifically, safety experts and educators, scientists, human factors engineers, and other researchers have conducted a wide variety of driving performance investigations on the road. Examples of the extensive research literature include mapping eye-movement patterns to the visual driving scene (Mourant & Rockwell, 1970), driver behavior patterns in traffic (Forbes,

Schmidt, Nolan, & Vanosdall, 1974), elderly drivers' perceptions of ability as compared to visual skills and driving performance (Fox, 1989), car-following in traffic (Brookhuis, De Waard, & Mulder, 1994), and an examination of an auditory route-guidance system (Green & George, 1995).

Road Evaluation for Occupational Therapists

Occupational therapists (OTs), the focus of the present study, represent another group that uses on-road evaluation. Occupational therapy (OT) is based on helping challenged individuals to develop and function independently within their environment. The OT has traditionally been involved with the daily living task of mobility, including bed and wheelchair mobility, transfers, and functional ambulation (Cox, 1989), allowing an individual to live independently and move about from one location to another. OTs are also involved in assisting with automobile driving. The ability to drive allows a person to remain independent by providing the mobility and freedom for daily living (Cox 1989), such as going to work, play, or shopping. For people who may have specific conditions that inhibit them from driving safely, OTs often help make driving easier by providing skills and/or necessary equipment (Cox, 1989).

OTs are involved in driver training and evaluation of people with a variety of disabilities, including the head-injury population, individuals with diabetes, dementia, Parkinson's disease, Alzheimer's, and the elderly. These may be people who have moderate to severe physical or cognitive impairments, multiple medical conditions, neuromuscular or neurological impairments, or progressive diseases, and they often require a referral (usually from a medical doctor) to a formal OT driver-evaluation program. People who have mild impairments require referrals only if there is specific cause to question their

driving safety (Lillie, 1993). From a medical point of view, Miller and Morley (1993) state that driver-training programs that utilize the services of OTs to assist physicians in the evaluation of drivers can be helpful in directing driving recommendations; the goal of such programs is to keep persons functioning in society as independently as possible, without sacrificing safety.

OTs evaluate abilities related to driving skill; they teach appropriate attitudes, road courtesy, and defensive driving, identify and teach safe compensatory techniques, and select and train in the proper use of adaptive equipment. This equipment may include special adaptive devices, including hand controls for braking and accelerating, modified steering systems, left-foot accelerators, and special mirrors (Cox, 1989). While cognitive and other driver performance measures are widely utilized in evaluating drivers, an on-road test is used in most OT evaluation programs. A typical OT road test consists of 30-90 minutes of driving, including vehicle control orientation, parking lot, residential, and business driving, a variety of maneuvers (e.g., lane changes, turns, stops), and sometimes freeway driving. Typical DMV road tests range from 10-60 minutes with an average examination lasting 20-30 minutes (Shumaker, 1994).

Off-road tests. OTs who become certified to teach driver training are involved in more than just on-road testing. Off-road tests, including assessment of visual perception and motor and cognitive skills, are also necessary (Irwin, 1989). For example, findings from a nationwide questionnaire sent to 200 OTs showed that they vary widely in their assessment of driving performance. While many rely on clinical judgment rather than standardized tests to determine driving ability, sixty-five percent of OTs reported using cognitive evaluations of their own design (Hunt, 1994). This included an assortment of simple tests to

detect sensory and perceptual abilities related to driving (e.g., reaction time, cognition) such as clinical vision tests, (e.g., peripheral visual field, depth perception, color sensitivity, static and dynamic visual acuity, and figure-ground discrimination), a range of motion and strength tests, such as neck rotation and grip strength (Cox, 1989), reaction time tests, and cognitive and memory tests (e.g., trail making, sign recognition, mental status, selective attention, and judgment). Another simple test, commonly used for static visual acuity, utilizes an eye chart. While the use of static acuity as a prediction of clarity of vision for driving does not seem realistic, dynamic visual acuity, which seems better, is used by OTs (Fox, 1989). Cox (1989) adds that neck rotation, grip strength, and reaction time are used as part of an OT evaluation of drivers in examining motor skills and driving ability.

The question of which tests predict actual driving performance has been ongoing, but generally the tests are used to assist the OT in making a clinical judgment about the patient's ability to drive. If such tests indicate that driving ability is sufficient, then the evaluation and training process continues to the on-road test. While standardization of evaluation procedures is lacking, most OTs report that a road test is still necessary in order to determine driving fitness (Hunt, 1994).

The OT evaluation paradox. On-road driving evaluations are the main platform for OT assessment due to a variety of benefits. Benefits include actually seeing the driver in action (as opposed to paper and pencil, knowledge tests) where specific behaviors, habits, and skills can be observed. Further, when teaching or evaluating driving, immediate feedback can be given. Behavior reflecting an understanding and incorporation of such feedback can be

monitored quickly, and driving skill can be assessed during the evaluation session.

However, there are some serious limitations to on-road driver evaluations including those related to weather and traffic restrictions, vehicle maintenance and expense, pollution, and perhaps most importantly, safety and liability. Not surprisingly, on-road driving evaluations can be dangerous: the combination of a potentially-impaired driver with an unfamiliar vehicle (the vehicle used is seldom owned by the person being evaluated) creates a potentially hazardous situation. Indeed, the opinion expressed by many OTs is that although the on-road evaluation seems to be the ultimate in evaluating driver performance, the risk associated with each ride is high. Consequently, most evaluations are limited to daytime driving, in relatively safe areas (e.g., residential neighborhoods, parking lots). Further, for reasons of cost, safety, and liability, few evaluations are administered in challenging, stressful, complex, or "unexpected" driving conditions (e.g., driving at night, in rain or fog, or in heavy traffic).

Thus, the paradox of on-road evaluation exists: The road evaluation is the most commonly used and presumably the most effective form of driver evaluation, but it is limited to driving during the daytime, in safe environments where driving is easy, unchallenging, stressless, and least representative of potential accident situations. Driving in such conditions maximizes the safety of the evaluation but greatly limits the value of conducting on-road evaluations. Stated another way, the potentially most informative method of driver evaluation is rendered *uninformative* by the fact that it does not represent the range of real driving conditions and cannot be carried out in a manner that challenges the relevant abilities of the driver being evaluated.

On-road safety. There have been few reported accidents during on-road evaluation, although little data exists on this topic (C. Beatty, personal communication, November 17, 1995). Accidents during evaluation are few because the amount of on-road evaluation time is relatively small and is spent mainly on basic maneuvers in safe, "normal" conditions (Andre, 1993). Also, there is a reduced chance of accidents due to the extensive training of the instructors (e.g., 300 hours) in the proper use of dual controls, such as instructor gas and brake pedals, and steering wheels that are added to many evaluation vehicles.

With little data available on the OT accident rates in driver evaluation sessions, the number of near misses reported necessitating evaluator intervention (e.g., controlling steering wheel, braking) and the level of stress experienced by driver assessors is high (S. Lillie, personal communication, November 8, 1995). With the continuous growth in the number of drivers on the road and a rise in the number of people needing driver evaluations, an increasing need for evaluation is apparent. Further, with a small number of driver evaluators available and the expense involved, the need for a more efficient evaluation process is dictated. Budget cuts and the limited resources for training, combined with an increased need for qualified driving evaluators puts pressure on existing evaluation programs. For example, the 3 full-time OTs at the Santa Clara Valley Medical Center perform on-road evaluations daily, and have had a waiting list ranging from two weeks to twelve months for potential clients. They currently are experiencing hospital-wide budget cuts in the millions of dollars.

An Alternative Approach

With such pressure, evaluations can be inefficient because of the need for specialized evaluation vehicles (e.g., vans for wheel chair drivers, dual control automobiles), the extensive, time-consuming but necessary OT training, and driving limitations (e.g., daytime, weather). In summary, to increase the efficiency of such programs, new assessment tools are needed to complement or replace the on-road evaluation.

Driving Simulator. A promising alternative for conducting driver performance evaluation may be some form of a driving simulator. As an assessment tool, the modern, computer-controlled, interactive driving simulator has enormous potential benefit, especially when used to test drivers of unknown driving ability. With the increasing number of evaluations needed and the always present threat of mishap on the road, a driving simulator seems a reasonable choice for controlling costs and improving safety. Simulation technology is now being used or is being considered for driver evaluation, training, and licensing (e.g., see Transportation Research Board, 1992). Human factors researchers have used and are using simulation to measure driver performance objectively (e.g., steering and braking behavior, heart rate, blood pressure, eye movement behavior). In addition, observational methods, used by DMV evaluators and OTs for road evaluations, might be applied to evaluations done during an interactive driving simulation.

What is a simulator? The word "simulate" is defined as fabricate, feign, pretend, copy, mimic, or imitate (Transportation Research Board, 1995) or as referenced by Sanders (1991), simulation is defined as a "technique of substituting a synthetic environment for a real one, so that it is possible to work

under laboratory conditions of control." Simulation was created in order to provide a safe, alternative representation believed to be a valid substitute for various aspects of a particular task (Allen et al., 1995; Andre, 1993; Bookout, 1993; Repa & Bertollini, 1990; Wachtel, 1995). In such an experimentally controlled environment, performance measures can be defined, collected, and repeated in a cost-effective manner.

Types of simulators. Simulators have been categorized as interactive and non-interactive (McKnight & Stewart, 1990). An advantage of an interactive driving simulator is that the simulator responds to the driver just as the driver responds to the simulator. This is also known as a closed-loop driving simulator (Cox, Gressard, Quillian, Westerman, & Gonder-Frederick, 1992). In a non-interactive system, the driver responds to the simulator, but the simulator does only what it was programmed to do, regardless of the driver's actions. Only limited evaluation information can be obtained in this system type, often referred to as an open-looped system (Cox et al., 1992). For this study, an interactive (closed-loop) simulator was used.

Interactive driving simulation represents actual roadways through computer generated imagery (CGI), auditory feedback, and realistic vehicle instruments and controls such as brake pedal, steering wheel, turn signal indicator, speedometer, and mirrors. The roots of driving simulation first appeared at least 85 years ago (Wachtel, 1995) with Munsterberg's response tests. Since then, simulation methods have continued to be used successfully. According to Marowitz (1991), during this same period Stern had participants press a key when certain letters appeared on a moving conveyor belt, and Sachs used patterns punched in the belt to represent pedestrians or other vehicles.

Driving ability was measured in correct responses under varying conditions. Such conveyor belt simulation was modified and used through the 1970's to investigate major causes of actions leading to accidents. However, much of the driving simulation research was temporally halted, due to the need for researchers and designers to assist with the re-design of our nation's airplanes. This emphasis on aviation has led to extensive development and usage of flight simulation for training, certification, etc. (Bookout, 1993).

Aviation simulation: Lessons learned. While flight simulators are expensive and on the high end of the cost spectrum of simulators, a wide range of simulators exists. Caro (1988) gives a variety of examples, from the early Link trainer, which was a 1929 training device that simulated the instrument environment of an aircraft, to a multi-million dollar Phase II flight simulator as used by pilots of major airlines such as United Airlines. Imagine training, assessing, and certifying pilots on a regular basis in not-so-friendly skies in airliners alone! Pilots are now regularly trained by the utilization of simulation technology. Such technology, which has been advanced largely due to the funding by the military for advanced aircraft training systems (Bookout, 1993), has made flying safer, pilots and their crews more effective, and airplane (cockpit) designs that are significantly enhanced (e.g., see Caro, 1988). Further, training simulators have been used widely and accepted in the aviation community for over forty years because of their proven ability to enhance the crew's performance in a safe and cost-effective manner (Andre, 1993). For example, Caro (1988) notes that Federal Aviation Administration (FAA) rules now permit experienced pilots to complete all of their initial training and checking for particular aircraft in simulators. FAA inspectors use simulators for

pilot performance evaluations for pilot certificates. This includes witnessing piloting skills that are either identical to the skills the applicant would evidence with the actual aircraft or approximations that would transfer without further practice or training (Caro, 1988).

Uses of Driving Simulators

In a similar fashion, simulation technology as used for driving evaluation, and eventually driving licensing, can include various realistic traffic situations such as one would encounter in every-day and, perhaps emergency driving situations. Although, ideally, one could perform driver evaluation in a realistic manner on-road, such assessment amid public traffic is dangerous, uncontrollable, and for ethical reasons should not be conducted unless risk of exposure to threats or dangers of the road are minimized (Alm & Nilsson, 1994). A driving simulator offers a safe, standardized, and controllable alternative for conducting such evaluations.

Various driving simulators exist (see Diewald, 1995; Federal Highway Administration, 1995; McKnight & Stewart, 1990) that range in their cost and fidelity. It seems likely that realistic, interactive driving simulators could be used to train drivers before and during actual driving takes place, and even for driver licensing. Already, a more realistic, flight-quality driving simulator is being developed. Called the National Advanced Driving Simulator (NADS), this \$32 million simulator will be used to study how motorists cope with potentially dangerous traffic situations without endangering the test subjects and to examine intelligent vehicle highway systems (IVHS) [recently renamed intelligent transportation systems (ITS) (Douglas, 1995)], and other highway and automotive designs (Gunby, 1992b). Expected to be completed by 1998 (Diewald,

1995), NADS shows the degree to which the federal government is willing to invest in driving simulation. However, the validity of this and other driving simulators remains to be demonstrated.

Low-Cost Driving Simulators

While both advanced and low-cost simulation allow safe, reproducible maneuvers that can be easily controlled and replicated in an experimental setting (Wachtel, 1995), low-cost microcomputer and display system technology has recently been developing at a rapid pace. The costs of many of the key components have fallen drastically, while the capabilities have increased significantly to support a range of simulator applications (Allen et al., 1995; Andre, 1993; Bookout, 1993). Further, low-cost driving simulators have been found to be useful for research purposes. They are continually being refined, have become more accessible, and include features that make them easily programmable (Allen et al., 1995). These refinements allow an even wider variety of investigators and other users to assess driver performance more easily.

Uses of low-cost simulation for research. Low-cost simulators have been used successfully for a variety of research applications. Examples include studies of the effects of alcohol intoxication on driver performance and choice to drive (Cox et al., 1992), evaluation of driving performance in patients with juvenile macular dystrophies (Szlyk, Fishman, Severing, Alexander, & Viana, 1993), investigation of performance, velocity, cognition (memory), and gender (Sexton, 1994), relative effects of age and compromised vision on driving-related skills and on-road accidents (Szlyk, Seiple, & Viana, 1995), and screening truck drivers for the effects of fatigue (Allen, Rosenthal, & Parseghian, 1995). They also have been used in monitoring driver drowsiness and in measurement of the

interference effect of in-vehicle IVHS (ITS) tasks on driving performance (Allen et al., 1995), as well as in a driving simulation based on virtual environment technology utilizing a head-mounted display (HMD) worn by the user (Levine & Mourant, 1995).

Uses of low-cost simulation for training and evaluation. Low cost simulators are now being used for practical applications such as procedural training of police officers and for the training and evaluation of older drivers (Mauger, 1994; Nowicki, 1994; Time Warner Interactive Simulation Products, 1993, 1994).

In the future, due in large part to limitations of the current DMV road test, simulation can be used for assessing the population at large, by evaluating, training, and eventually granting licenses (McKnight & Stewart 1992; Peck & Wachtel, 1993; Transportation Research Board, 1992). For example, with the guidance and input from various police training agencies around the country, a low-cost interactive simulator has been used for training exercises emphasizing the coordination of tactics, reinforcing compliance with organizational policy, and dispatcher instructions (Olsen, 1995).

Simulator sickness: A potential downfall. One disadvantage of any simulator is that as the number of images in the virtual environment increases, "there is a concomitant increase in the transport delay" according to Frank, Casili, and Wierwille (1988). This delay is a result of the limitations in computing power of the microprocessors used for the simulator. As the number of objects (e.g., vehicles, building, signs, pedestrians) increases, the greater the calculation time and thus an increase in the delay that an image appears on the screen after a driver response input.

Such delays can cause degradation in performance and may increase the likelihood of discomfort, uneasiness, or *simulator sickness* experienced by the user. Simulator sickness is a form of "visually induced motion sickness," that is, "simulator sickness or discomfort is similar to motion sickness, but it can occur without active motion of the participant" (Kolasinski, 1995). While it is believed that the causes of simulator sickness are visual, it is quite likely both "polysymptomatic" and "polygenic" (Casili & Wierwille, 1986; Kennedy & Frank, 1986). For this study, a brief review of simulator sickness theories and factors of simulator devices that may influence participant discomfort is justified.

Several simulator sickness theories exist (see Kennedy & Frank, 1986). Perceptual conflict or cue conflict theory is the most widely accepted theory of simulator sickness (see Kennedy, Kettinger, & Lilienthal, 1988 for a minor distinction between the two). Perceptual conflict occurs in a fixed-base simulator where there is disparity between the visual system and the vestibular system. While driving the simulator, the eyes perceive motion while the body senses no motion, thus a conflict occurs. However, according to Frank, Casali, and Wierwille (1988), the precise cause of simulator sickness is not known. Other factors such as wide field of view (FOV) may elicit simulator sickness. A system offering a wide FOV provides the opportunity for more stimulation in the periphery. Such perceived movement has been known to induce discomfort and may have been an influence in wide FOV devices such as some Air Force, Navy, and driving simulators (Casili & Wierwille, 1988). A variety of other factors, such as update rate, temperature, ethnicity, gender, experience, and cab enclosure may affect likelihood of simulator sickness (Casili & Wierwille, 1986; Kennedy & Frank, 1986; Kolasinski, 1995).

While the exact percentage of people reporting simulator sickness seems to be unknown and possibly under-reported, Kennedy, Fowlkes, Berbaum, and Lilienthal (1992) report that the incidence among Navy pilots may vary from 10% to 60%, and depends on pilot and simulator characteristics. Participants of a recent workshop discussing driving simulation reported that a range of 1% to as high as 20 or 25% of subjects were affected by such sensory conflicts (Transportation Research Board, 1995).

The benefits of driving simulators. Much driver research indicates that the utilization of simulation technology may have the potential to save billions of dollars in life, property, and insurance costs (Transportation Research Board, 1992) in the next 30 years. Already, simulators are being used because of safety and cost concerns. For instance, the wide-spread popularity of low-cost simulation for police training has stemmed from an alarming increase in pursuit-related costs, accidents, and fatalities. Costs associated with the entire nation's police pursuit costs are measured in billions of dollars (Auten, 1994). A large portion of this could be saved by improving police driving training alone. With costs and potential savings such as these, it can be easily seen that the benefits of simulation for driver safety are important to explore.

The Present Study

The purpose of this study is primarily to determine if a driving simulator can be used to accurately and efficiently measure driving performance as compared to an on-road evaluation, and additionally, to identify differences between road and simulated driving. In order to properly evaluate drivers using a driving simulator in place of currently used driving evaluations, the following question must be answered: Can a simulator serve the purpose of an on-road

evaluation? Using a driving simulator for evaluation purposes may assist OTs to be more efficient in their client evaluation work, allow more people to continue to drive in a safe manner, and maximize the effectiveness of the transportation system of our society. By assessing the skills and abilities of drivers with a simulated driver evaluation as compared to an on-road evaluation, it can be determined if a simulator could be used effectively by OTs in place of an on-road evaluation.

For this study, a low-cost interactive simulation was used. This driving simulator is completely interactive in that actions of the subject or failures to act in certain situations influence the visual display that closely reflects experiences of actual driving (Janke, 1994). Various versions of this driving simulator have been used for a variety of experimental and pragmatic applications. The current study hopes to expand upon previous and on-going work in yet another application of such technology. While flight, driving, and other simulators have been and are being used extensively, questions remain as to the appropriateness and validity of their application. Can a simulator be used for longer, whole-task driver evaluation or assist part-task assessment? Most applications thus far have been limited to either short scenarios or jumps (e.g., 3-5 minutes) or for longer sessions (10-30 minutes) with very limited maneuvers, such as with straight road or highway driving (e.g., McGehee, Dingus, Papelis, & Bartelme, 1995; Sexton, 1994). This is not to say that useful findings have not been obtained, but this study attempts to assess driving in a realistic, whole task setting such as one would encounter when driving on the road, utilizing a low-cost, interactive driving simulator.

One problem with driving simulation studies has been the inability to compare on-road driving performance to simulator performance. Such comparisons are important in determining if a driving simulator can be used to measure driving performance. However, the few studies that have directly compared road performance to simulator performance have done so mostly on very expensive, elaborate, motion-base simulators. Now, with low-cost, interactive simulators available, such comparisons are more feasible. While the problems of simulators, and specifically driving simulators, continue to exist, it is to be determined whether the potential benefits will outweigh the limitations of using simulation.

Method

In the present experiment specific driver information was collected through self-reported Driver History and Cognitive Failure questionnaires (see Table 1) from a range of licensed drivers between the ages of 18 and 75. In addition, a driver reaction time test was administered to all participants. Finally, both on-road and simulated OT driving evaluations were administered in a counterbalanced fashion.

Design

A 2 X 2 mixed factorial design was employed with driving Environment (Road and Simulator) varied within subjects and Age (Younger < 45 years, Older > 45 years) varied between subjects.

Participants

The 19 participants in the study were licensed drivers (age 18-75). All participants had normal or corrected-to-normal vision and valid California drivers licenses. The participants were recruited through newspaper and posted

Table 1. Tests Used to Collect Data on Abilities Related to Driving Skill

Driver History:

Age

Accidents (within last five years - Yes or no)

Tickets (within last three years - Yes or no)

Cognitive Failures Questionnaire:

Rating of self-reported failures

Driving RT Test:

Simple Reaction Time

Driving evaluations:

Road performance

Simulator performance

advertisements that offered \$5.00 per hour to healthy drivers for participation in an experiment involving an on-road evaluation and a driving simulator.

Participants were recruited through a local university, a hospital, and a local senior center. Of the 14 participants who completed all sessions of the study, 10 were in the Younger group and four were in the Older group.

Apparatus and Stimulus

Orientation. Upon arrival, verification of both a current driver's license and proof of automobile insurance was carried out. The first portion of each session included an orientation in which the purpose of the study was explained (see Appendix A) and various forms were completed as required by the Santa Clara Valley Medical Center. Also, the Driving Questionnaire, shown in Appendix B, was used to determine basic driving information.

An additional questionnaire, the Cognitive Failures Questionnaire (CFQ) (Broadbent, Cooper, FitzGerald, & Parkes, 1982), was also completed (see Appendix C). The CFQ asks questions of participants about minor mistakes, lapses of attention, or instances of forgetting that occur from time to time. This questionnaire, previously utilized in a driver study by Andre (1991), was used to assess self-reported failures in perception, memory, and motor function in drivers.

Driving Reaction Time Test. The reaction time test was administered to determine simple reaction time, utilizing the Instructo-Clinic Testing Apparatus (Bumpa-Tel®, Inc., 1973). This apparatus is for testing depth perception, visual acuity, peripheral vision, color determination, and simple and complex reaction time, and was used to test and measure simple reaction times in this study. The unit consists of simulated gas and brake pedals with a series of red, yellow, and

green lights to test reaction time. The task involved depressing the gas pedal to illuminate a green light. When the red light was activated, the participant was to brake as quickly as possible by stepping on the brake pedal. After a series of practice trials, three trials were given; the average of these three trials was reported.

On-Road Evaluation. The driving evaluation for this study was based on the Adaptive Driving Evaluation Program at the Santa Clara Valley Medical Center (SCVMC). The on-road evaluation was conducted in SCVMC's 1989 Oldsmobile Cutlass Cierra evaluation vehicle, with column shift, power seat adjustment, power assisted steering, and dual instructor brake.

The on-road route was designed to allow a variety of typical, everyday driving situations to be encountered. This route included parking lot driving, and both business and residential street driving up to 40 m.p.h. No freeway driving was included.

Simulator Evaluation. The simulated drive evaluation used a Time Warner 5-screen driving simulator, equipped with standard vehicle controls, including turn indicator, column shift, seat belt, and steering wheel (Figure 1). This is a single-operator unit in a configuration that produces a 225-degree panoramic field of view (Nowicki, 1994). Each of the 25-inch screens has a resolution of 512 X 384 pixels. The frame update rate varies from 12-20 frames/sec (12-20 Hz) depending on how many vehicles are in the scene at any one time. A series of microprocessors compose the system including a sound microprocessor that generates realistic auditory feedback (e.g., tire skidding sounds when stopping or turning too sharply).

Figure 1. Time Warner 5-Screen Simulator

According to Time Warner Interactive Simulation Products (1994):

The simulator is controlled by a network of microprocessors which update the simulated vehicle's position and the driver's viewpoint. A mathematical model of vehicle dynamics gives the simulator its realistic response to road conditions and the driver's controls. Typical vehicle dynamics characteristics such as acceleration, suspension reaction, braking, and cornering forces are included in the model calculations. The driver's "hands-on" feel of the vehicle is simulated by physical forces transmitted through the steering wheel. Road and engine vibrations are additional forms of physical feedback (transmitted through the steering wheel and seat).

Similar to the on-road route, the simulated evaluation route was designed to allow a variety of typical driving situations to be encountered. This route included business and residential street driving up to 35 m.p.h. No freeway driving was included.

The route characteristics of the simulated drive portion of the experiment had many similarities as compared to the on-road route (see Table 2). For example, the mileage, duration and number of left turns, stops signs, lane changes, and backing up and parking maneuvers were approximately the same for both environments. However, some aspects, such as the number of right turns, traffic signals, U-turns, three-point turns, vehicles, and speed signs differed between the two environments.

Table 2. Common Aspects Between the 2 Environments

	<u>Road</u>	<u>Simulator</u>
Mileage	8.3 miles	7.8 miles
Duration	25-35 mins.	24-35 mins.
Left turns	11	10
Right turns	12	19
U-turns	3	1
3-point turns	1	3
Traffic signals	11	21
Stop signs	10	11
Speed signs	9	3
Lane changes	5	5
Backing up	2	2
Parking	2	2
Vehicles	100 s	97

Limitations of the simulator route accounted for the dissimilarities; the lack of long roadway segments resulted in the need to increase the number of right turns to allow the simulated portion to include approximately the same mileage as the on-road portion. The higher number of light signals in the simulator, as well as the lower number of pedestrians, bicycles, and vehicles was also a limitation of the simulation system. Likewise, the lower number of pedestrians, bicycles, and vehicles, and speed signs was a limitation of the simulated road program (i.e., the more objects that were present at any one time, the slower the update and processing rate of the system).

The differences between the environments seemed acceptable. For instance, the lower number of U-turns on the simulator was compensated for by an increased number of three-point turns, which involved the same sorts of driving skills and abilities as a U-turn. Another limitation of the simulator was the fewer number of vehicles and pedestrians encountered. Although it was very important to assess one's ability to properly respond to traffic on-road, the simulator allowed specific, typical driving situations to be programmed. Participants encountered fewer vehicles during the route, but the evaluator was able to successfully score the participant's performance during these expected driving situations. The final potential limitation of the simulator was the potential for simulator sickness.

Simulator Sickness Countermeasures Taken. To minimize the likelihood of simulator sickness incidence, the following countermeasures were established: Participants were informed that the session could be paused or terminated for any reason at any time. Water, sugar candy, and snack bars were made available. Participants were given a 4-minute orienting exercise, consisting of simple

maneuvers, during which the participant had a chance to become familiar with the simulator and the objects in the simulated universe. Participants were required to get out of the simulator between the orientation and the 30-minute evaluation portion. The 30-minute simulator evaluation was divided into three 10-minute segments. After each segment, the participants were allowed to get out of the simulator. Water and restroom breaks were offered at these times. Before resuming the next session, participants were also reminded that the session could be paused at any time. An external fan was used to increase circulation in the experiment room. The overhanging glare cover of the simulator was positioned one foot back from its recommended position. This served to lessen a of feeling enclosure, that may contribute to simulator sickness. The room was air conditioned. The thermostat was set at between 68 to 70 degrees Fahrenheit. A restroom, just outside the experiment room, was available. The evaluators monitored each participant for warning signs of discomfort caused by the simulator (e.g., sweating, nervousness). For participants who experienced discomfort, a chance to rest and relax was given. An outside patio was available for breaks. Before exiting the simulator, the simulated vehicle was stopped.

Procedure

Each participant completed a three-hour orientation and data collection session. Some sessions were completed in one, two, or three visits, due to time and schedule constraints. This was due to the availability of the experimenters, the participants, the evaluation vehicle, and the evaluation/driving simulator room. After completing a 25-minute orientation, which included completion of a series of forms, each participant took part in a 3-5 minute Driver Reaction Time evaluation. Water and restroom breaks were offered at the end of each portion.

Following this, participants drove the on-road route and the simulated drive route portions in a counterbalanced fashion.

Each driving portion of the experiment was divided into two parts: In the first part, participants were allowed to become familiar with the vehicle and its controls. For the on-road portion, this included a 5-minute review of the turn signal controls, mirrors, brake and acceleration pedals, horn, and a brief driving portion through a parking lot toward the actual route. For the simulator, the orientation included a similar review of the vehicle controls, and a "4-minute orientation" while driving the simulator. This driving orientation gave participants a brief experience with the simulator so they could better understand how the roadway and vehicle dynamics were portrayed (e.g., lane markings, curbs, traffic lights, vehicles).

For the second part of each driving portion, participants drove a 30-minute route. For both the on-road route and the simulated route, the same experimenter administered the orientation and the route instructions. This person was a registered Occupational Therapist who had completed a standard 60-hour Driver Instructor Course and was certified by the Department of Rehabilitation as an Adaptive Driver Evaluator. Another experimenter collected driver performance data by way of the Driving Results Form (Appendix D) for each environment (i.e., for each environment a different experimenter scored each participant). The main benefit of having 2 different experimenters to collect driver performance data was that once a scorer sees how a person drives it would be difficult, if not impossible, to pre-judge them and not be biased in the other driving condition. The experimenters who scored each driver were trained in a similar manner to increase the likelihood of high inter-rater reliability for the

experiment ($r = .99$, rank-order inter-rater reliability, $n = 3$). The scorers did not provide instructions, but fulfilled an observation role only. The scorers were positioned behind and to the right of the participant for each evaluation (see Figures 2 and 3) and completed observations of performance using the Driver Results Form.

Instructions for the "4-minute orientation exercise" administered to familiarize each subject with the simulator are shown in Appendix E. A similar set of instructions was administered for the 30-minute simulated drive evaluation (Appendix F), and for the orientation and 30-minute on-road drive evaluation (Appendix G). The maps depicting the routes used in each environment are shown in Figures 4 and 5.

The evaluation technique for the on-road evaluation followed the same criteria as the simulated driving evaluation: An Overall score, consisting of Steering, Braking, Accelerating, Caution/Safety Awareness, and Additional Driving Skills, was assessed using a 33-item version of a standardized scoring sheet (see Appendix D). Each of the thirty-three items was completed, based on a 5-point scale, 0 representing failure, 1 representing poor performance, 2 representing marginal performance, 3 representing satisfactory performance, and 4 representing consistently good performance.

Training of scorers

To attain a high inter-rater reliability the following training took place: 1) Discussion of each of the 33 items of the questionnaire took place. This served to more thoroughly explain what the scorer was looking for when scoring each item. A review of behaviors and actions was discussed that would result in scores ranging from poor (0) to consistently good performance (4). 2) Several

Figure 2. Test Administration, Scoring, and Set-up for Simulated Drive

Figure 3. Experimental Room Set-up & Simulator - Top View

Figure 4. On-Road Route Map

Traffic Light
Stop Sign

Map not to scale

Figure 5. Simulator Route

ride-alongs were completed. During these ride-alongs, the experimenter who gave directions during the actual experiment reviewed what sort of behaviors or actions the scorer would be looking for during an evaluation. 3) During two of the ride-alongs, the experimenter giving directions, the experimenter acting as the on-road scorer, and the experimenter acting as the simulator scorer rode together to discuss scoring, item by item along the route. 4) A similar process was followed with a ride-along with the simulator, after which discussion took place about scoring along the simulated route. 5) As a final step, both scorers went on three ride-alongs with a pilot participant on-road and each separately scored the participant using the score sheet. Discussion took place afterwards and each item on the score sheet was compared for consistency in scoring. 6) A pilot participant was independently scored by the two scorers in the simulator as well, but the entire session was not completed, due to time constraints. 7) Inter-rater reliability was calculated. A total of three participants were scored on the road by both experimenters. The rank order inter-rater reliability scores for the three subjects were 0.995, 0.989, and 0.989 with a mean of 0.991.

Post experiment procedure

A debriefing interview (Appendix I) was conducted to access each participant's subjective experience and to elicit input.

Analyses

The data were analyzed for the 14 participants who completed both the on-road and simulator evaluations. Correlation and regression analyses were conducted, and scores across environments and between age groups were compared utilizing both an ANOVA and a MANOVA technique.

The dependent variables were analyzed as a function of Environment (Road and Simulator) and Age (Younger and Older). These were divided into three types of measures — driving performance, driving reaction time, and driving history data. The driving performance score measures consisted of the Overall Performance, Steering, Braking, Acceleration, Caution/Safety, and Additional Skills. The driving reaction time was an average of three trials of simple reaction time. The driving history measures were number of accidents, number of tickets, and a score from the CFQ (for variable abbreviations, see Table 3).

Results

The ANOVA and MANOVA analyses allows comparisons between conditions to determine what differences (or similarities) exist. The regression analysis examines the predictability of evaluating components, in that non-related measures (e.g., age) can be compared to performance scores to see if these measures serve a predictive ability. In doing this, one may discover that knowing how one performed on a particular component (e.g., of a driving evaluation) would predict their performance for the entire set of components (e.g., the entire examination).

Participant Mortality

Simulator Sickness. It is important to note that of the 19 participants who began the study, only 14 were able to finish the simulator session. Of those 14, 6 reported some uneasiness, but were able to finish the session. Only 8 of the 14 (58%) reported no uneasiness, as indicated in Figure 6. The drop out rate (26.3%) seems to have been a result of simulator sickness experienced by these participants.

Table 3. Variable Abbreviations

<u>Abbrev.</u>	<u>Variable</u>	<u>Measure</u>
Age	Age Group	0 = young, 1 = old
CFQ	Cognitive Failures Questionnaire	max = 100
RT	Reaction time	seconds (average)
Acc	Accidents	within 5 yrs; 0 = no, 1 = yes
Tx	Tickets	within 3 yrs; 0 = no, 1 = yes
Rsc	Road Score (Overall)	sum (33 items)
Ssc	Simulator Score (Overall)	sum (33 items)
Rst	Road Steer Score	sum (5 items)
Sst	Simulator Steer Score	sum (5 items)
Rbk	Road Braking Score	sum (4 items)
Sbk	Simulator Braking Score	sum (4 items)
Rac	Road Accelerating Score	sum (6 items)
Sac	Simulator Accelerating Score	sum (6 items)
Rca	Road Caution/Safety Awareness	sum (14 items)
Sca	Simulator Caution/Safety Awareness	sum (14 items)
Rad	Road Additional Driving Skills	sum (4 items)
Sad	Simulator Additional Driving Skills	sum (4 items)

Figure 6. Uneasiness of Participants

Overall Driver Evaluation Scores

Environment. The question of interest involves comparing overall road driver performance scores to simulator driver performance scores to discover if order is preserved between the two environments. In other words, does a driver who scores "good" in one environment score "good" in the other environment? To begin to answer this question the scores for each participant were grouped into categories of performance, following the categories for the overall score from the Driver Results Form (Appendix D). These were "Good" (119-132), "Fair " (99-118), "Needs Training" (80-98), and "Poor" (<80). The Pearson Product-Moment correlation (r) between these categories for Road and Simulator is .14 ($p > .10$), signifying a low relationship between conditions. While all participants were rated above the "Poor" category, 50% of participants received a score for one condition that differed from their score for the other condition. Approximately half of the people who were rated "Fair" for one condition, were rated "Needs training" in the other or vice versa.

On the other hand, the correlation (r) between Overall Road Score and Overall Simulator Score is .41, $p = .07$ (17% of the variability is accounted for) as shown in Table 4 and depicted in Figure 7. For the actual data in this experiment, while the relationship did not reach statistical significance, it is encouraging to see a moderate correlation with such a small sample size ($N = 14$).

Having looked at the order relationship between overall Road and Simulator scores, one can then ask, "Are evaluation scores consistently higher or lower in one environment than in another?" For example, it is possible that the driver performance as evaluated on the simulator might always be higher, because less feedback is available, as compared to actual driving on the road. If

Table 4. Pearson's R Correlation Matrix

	Ssc	Age	CFQ	RT	Acc	Tx
Rsc	.41	-.48	.23	-.50	-.29	.16
Ssc		-.05	-.14	-.52	-.09	-.60*
Age			.06	.57*	-.23	-.40
CFQ				-.11	.12	-.04
RT					-.30	-.13
Acc						.09

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* P < .05

TABLE 4. Pearson's R Correlation Matrix (cont.)

	Age	CFQ	RT	Acc	Tx
Rsc	-.48	.23	-.50	-.29	.16
Ssc	-.05	-.14	-.52	-.09	-.60*
Rst	-.15	-.40	-.27	-.08	-.06
Sst	-.10	-.34	-.33	-.07	-.17
Rbk	-.39	.14	-.68*	-.17	.09
Sbk	-.01	-.18	-.12	.10	-.72*
Rac	-.30	.23	-.28	-.49	-.19
Sac	-.31	-.03	-.75*	-.06	-.41
Rca	-.33	.24	-.37	-.20	.33
Sca	.24	-.10	-.26	-.11	-.75*
Rad	-.72*	.44	-.46	.02	.25
Sad	-.39	.08	-.69*	-.15	.15

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* P < .05

TABLE 4. Pearson's R Correlation Matrix (cont.)

	Ssc	Rst	Sst	Rbk	Sbk	Rac	Sac	Rca	Sca	Rad	Sad
Rsc	.41	.34	.44	.79*	-.05	.76*	.51	.90*	.26	.69*	.46
Ssc		.57*	.71*	.49	.70*	.38	.90*	.22	.92*	.07	.40
Rst			.53*	.32	.33	.13	.45	.16	.55*	-.01	.17
Sst				.28	.40	.24	.49	.40	.58*	.14	.24
Rbk					-.02	.60*	.66*	.62*	.36	.51	.59*
Sbk						-.06	.53*	-.17	.65*	.02	-.03
Rac							.46	.50	.34	.46	.39
Sac								.30	.73*	.26	.59*
Rca									.09	.56*	.32
Sca										-.17	.10
Rad											.36

* P < .05

(for variable abbreviation meanings, see Table 3)

Figure 7. Overall Road Score X Overall Simulator Score

($r = .41$)

simulator scores are consistently higher than the road scores, then the scale for simulator evaluation would have to be adjusted down. To answer the above question, an ANOVA was conducted on the Overall evaluation scores. This was performed to determine whether there were overall differences in scores. As shown in Figure 8, this revealed no main effect for Environment, $F(1,12) = 1.72$, n.s., as the mean Overall Road Score (101.21) and Overall Simulator Score (103.86) were roughly equivalent (see Table 5 for descriptive statistics). Thus, while there is not a highly reliable relationship between on-road and simulator assessment scores, the average overall score across drivers in both environments was the same.

Age. The correlation of Age and Overall Road Score was significant, as expected, indicating that Road Scores increased as Age decreased ($r = -.48$, $p < .05$) as shown in Figure 9. For Age and Overall Simulator Score, it was not significant ($r = -.05$, n.s.). The MANOVA revealed significant differences between age groups and for the two environments; there was no main effect for Age and no interaction for Age and Environment ($p > .10$).

Age, Accidents, CFQ, RT, and Tickets. A forward stepwise regression analysis was also performed to see if any of these components predicted overall simulator and road scores. Age, Accidents, CFQ, RT, and Tickets were regressed on both Overall Simulator Score and Overall Road Score. For the Overall Simulator Score, Tickets was entered first and accounted for 35.6% of the variability. RT was entered second and, together, Tickets and RT accounted for 72.1% of the variability, as illustrated in Figure 10. None of the other variables (Age, Accidents, or CFQ) was entered into the regression equation. For the

Figure 8. Main Effect of Environment on Overall Performance Score

Table 5. Descriptive Statistics (N=14)

<u>Abbreviation</u>	<u>Mean</u>	<u>Standard Deviation</u>
CFQ	32.57	10.68
RT	.46	.06
Rsc	101.21	9.44
Ssc	103.86	11.94
Rst	17.14	1.70
Sst	14.86	2.32
Rbk	9.86	1.03
Sbk	13.29	1.86
Rac	18.14	3.01
Sac	18.57	3.32
Rca	41.79	5.00
Sca	42.86	5.80
Rad	14.29	1.86
Sad	14.29	1.73
<u>Measure</u>	<u>Yes</u>	<u>No</u>
Acc	6 (43%)	8 (57%)
Tx	4 (29%)	10 (71%)

Figure 9. Age X Road Score

$$r = -.48$$

Figure 10. Regressing Age, Accidents, CFQ, RT, and Tickets
on Overall Simulator Score

Overall Road Score, none (not Age, Accidents, CFQ, RT nor Tickets) entered into the regression equation with an inclusion criterion of $\alpha = .05$. People in the Younger group had an average RT of .44, as opposed to people in the Older group, who had an average RT of .52. While only a moderate relationship exists between Overall Scores for Road and Simulator, one may learn more precisely where differences between the two environments lie. Let us next look at the sub-component scores as a function of Environment and Age.

Steering Sub-Component Scores

Environment. For the Road and Simulator, the Steering scores were significantly and positively correlated ($r = .53$, $p < .05$) as shown in Figure 11. The MANOVA revealed a main effect of Environment on the performance score for Steering, univariate $F(1, 12) = 13.43$, $p < .01$. As shown in Figure 12, steering performance on the Road was higher (17.14) than steering performance on the Simulator (14.86).

Age. The correlation of Age and Steering Score on the Road was not significant ($r = -.15$, n.s.), nor was the correlation for Age and Steering Score on the Simulator ($r = -.10$, n.s.). The MANOVA revealed no effect of Age on Steering Score, $F(1, 12) = .24$, n.s.

Braking Sub-Component Scores

Environment. For the Road and Simulator, the correlation between Road Braking Score and Simulator Braking Score was not significant ($r = -.02$, n.s.). The MANOVA revealed a main effect of Environment on Brake performance score, $F(1, 12) = 30.86$, $p < .01$. As shown in Figure 13, Braking performance was higher on the Simulator (13.29) than for the Braking performance on the Road (9.86).

Figure 11. Road X Simulator Scores for Steering

$$r = 0.53$$

Figure 12. Main Effect of Environment on Steering Performance Score

Figure 13. Main Effect of Environment on Brake Performance Score

Age. The correlation of Age and Braking Score on the Road ($r = -.39$, n.s.), and Age and Braking Score on the Simulator ($r = -.01$, n.s.) were both not significant. The MANOVA revealed no effect for Age and Braking Score, $F(1, 12) = .50$, n.s.

Acceleration, Caution/Safety, and Additional Skills.

Environment. For the Road and Simulator, the correlation between Road Acceleration Score and Simulator Acceleration Score was not significant ($r = .46$, n.s.), the correlation between Road Caution/Safety Score and Simulator Caution/Safety Score was not significant ($r = .09$, n.s.), and the correlation between Road Additional Skills Score and Simulator Additional Skills Score was not significant ($r = .36$, n.s.)

Age. The MANOVA revealed no main effect for either Acceleration $F(1, 12) = 1.78$, n.s., or Caution/Safety Skills, $F(1, 12) = .01$, n.s. The MANOVA did reveal a significant main effect of the Additional Skills sub-component, $F(1, 12) = 10.46$, $p < .01$. As shown in Figure 14, the participants in the Younger group scored higher (14.9) than the participants in the Older group (12.75). For the remaining categories of Acceleration and Caution/Safety no significant differences were found.

Discussion

The purpose of this study was to determine if a driving simulator can replace an on-road evaluation in the context of an Occupational Therapist Driver Assessment. Specifically, this study set out to compare the differences between the two environments. The benefits of using a simulator to perform driver assessment are many-fold and include: 1) a more time- and cost-efficient method for evaluations (e.g., weather concerns would be eliminated), 2) the ability to

Figure 14. Main Effect of Age on Additional Skills Performance Score

evaluate drivers under complex conditions where failures are likely to occur, and 3) the safety of both the evaluator and driver would be improved.

Unfortunately however, the data from this initial study does not show clear promise for replacing the current on-road assessment procedure with simulator assessment for OTs. This is based on the lack of statistically significant positive correlation between Road and Simulator, and the high drop out rate due to simulator discomfort.

By looking at the sub-components that make up Overall Performance (Steering, Braking, Acceleration, Caution/Safety, and Additional Skills) for each environment, one can better learn when and why road and simulator evaluations are associated. While both Acceleration and Additional Skills were not significantly correlated, a fairly positive relationship does exist.

Only one component, Steering, showed a positive and significant correlation between the environments of Road and Simulator. It is suspected that these findings are largely due to the differences in fidelity and feedback between the two environments examined here. Braking and Caution/Safety however, showed very low correlations. While the Braking was discussed previously (see the Braking Sub-Component Scores section), the low correlation for Caution/Safety seems to indicate that differences are readily apparent for each environment, such as where to look for traffic, how the vehicle (actual or simulated) responds, etc.

Overall Driver Evaluation Scores. The fundamental question of this study is whether or not a simulator-based evaluation leads to a different decision as does an on-road evaluation of driver competency. The moderate, positive, but not significant correlation ($r = .41$) between overall road and simulator scores

seems to indicate that utilizing the simulator to measure driver performance is not a strong predictor of road performance. This result is of primary importance, since this study is concerned with the relation between simulator and road scores. On the other hand, the MANOVA revealed no main effect for Environment, which indicates that the Road and Overall Simulator scores were equivalent. One must keep in mind that this finding may reflect the low statistical power and may apply only to this particular simulator in this particular testing environment.

Steering Performance Score. Steering performance was rated higher on the road as opposed to in the simulator. Complaints from participants about the steering in the simulator included "too sharp," "hard to steer," and "could not judge where curb was." This may explain why scores were significantly lower in the simulator. This section of the driver results form emphasized steering without weaving or cutting corners, and measured proper lane position and smooth steering wheel recovery.

Braking Performance Score. For braking, participants scored higher in the simulator. To better understand why braking score was higher, the Driving Results Form (Appendix D) was reviewed. In the braking section of the form, 4 items made up the total braking score. This interesting finding can best be explained by the differences in cues available to the scorers in each environment. In the simulator environment, there are fewer cues (vestibular, motion, kinematic) to provide feedback to the evaluator about the quality of braking as opposed to the road, where all braking activities have a more noticeable effect. Another cause for this effect may be that participants in the simulator seemed more cautious. For example, crosswalk markings in the simulator were very

apparent, that is, they appeared bright white on a dark background. The contrast of white on black was very easy to notice; therefore participants may have been more aware that a crosswalk for which they must stop or slow down was ahead. In addition, images such as lines appeared to flutter (due to "aliasing") and may have been more noticeable than if they had been stationary. With the actual road, the contrast may be low for such markings due to faded pavement (light gray) or faded cross-walk paint.

Another reason that participants may have scored higher (better) in the simulator, may have been due to the tendency of participants to stop well before crosswalks and intersections. This may be due to less depth perception cues (i.e., two dimensional screen), which caused participants to approach intersections with excess caution. In addition, since driving in the simulator is less familiar than driving on the road, participants may have consciously tried harder to brake carefully in the simulator. It is also possible that braking in the simulator was easier (e.g., the brakes were more sensitive) than in the car. Finally, the correlation between Road Braking and Simulator Braking was not significant ($r = -.02$) which means that predicting Braking performance on-road based on simulator performance (or vice versa) is not recommended.

Additional Skills Performance Score. Additional skills performance was higher (better) for the Younger. This measure deals with physically maneuvering the vehicle and includes extensive maneuvers that necessitate neck, trunk, and arm movements. It is possible that the older people had more difficulty with these skills, due to strength and range of motion restrictions typically encountered with age (McPherson, Ostrow, Shaffron, & Yeater, 1988).

Behaviors common between environments: OT observations. The occupational therapist involved in giving instructions for both environments was asked for her comments about assessing driver performance in the simulator vs. the road. The following is a summary of her comments.

The behaviors that can be observed on both the simulator and the road are specific behaviors, such as stopping past the limit line, an incomplete stop, hitting corners or curbs on right turns. For example one participant who hit the curb on the simulator would have done the same during the on-road evaluation had a steering wheel intervention not been given (to avoid collision). Participants who "ran" red or yellow traffic signals on the road did so on the simulator. Blind spot checks, visual scanning, and people's overall defensive driving skills could be monitored in both environments. For example, people who drive very cautiously (i.e., tend to look left-right-left and let traffic clear out) tend to do so on the simulator as well as on-road. Both positive aspects of driving skill as well as areas that needed improvement were observable in both environments.

Simulator Sickness. The drop out rate (26.3%) seems to have been a result of simulator sickness experienced by the 5 participants who could not finish the experiment. Simulator sickness is one of the most discussed topics among simulation experts, and still represents a major obstacle in using a driving simulator to replace on-road evaluations for driver evaluation purposes. Delays between subject responses and simulator scene updates can cause degradation in performance and may increase the likelihood of discomfort or uneasiness experienced by the user. While further study of simulator sickness is necessary, countermeasures were taken to minimize the likely occurrence of simulator

sickness as previously discussed. Further sickness countermeasures may be recommended, however.

Further recommendations to minimize simulator sickness. The following recommendations may assist in minimizing simulator discomfort. Keep room very cool at 66 to 68 degrees Fahrenheit. Have quiet, fan(s) on at all times. Consider a low breeze directly on the participant. Have operable fans inside the simulator for further ventilation. Orient the participant to the simulator with the screens blanked, before an image is presented. Always stop the simulated vehicle before exiting the simulator. Ideally the screen would blanked every time one exits or enters the simulator.

Further recommendations have been used in the recent literature. Grein (1995) suggests minimizing the initial driving exposure, minimizing turns, with an emphasis on smooth and steady steering, and having participants physically get out of the simulator between sessions or exercises. He also suggested that utilizing devices such as the Sea-Band®, which exerts pressure and delivers acustimulation to the Neiguan (P6) acupuncture point on the underside of the wrist, may minimize simulator sickness. In fact, in a field study by Bertolucci and DiDario (1995) it was found that utilizing a similar device, known as The Relief Band®, suppressed motion sickness symptoms associated with seasickness experienced on the open sea. Perhaps, such a device would be successful in controlling simulator sickness.

A final thought on the failure to support using this simulator for evaluation. While this particular simulator has been successfully used by various researchers and police agencies, the manner it has been used has minimized the amount of and effect of simulator sickness on driving performance. In these

applications, short driving sessions (3-5 minutes) and minimal maneuvering was used. Part of the point of the present study was to replicate, as closely as possible, an on-road evaluation, utilizing a simulator. The bottom-line finding is that, *as utilized*, this simulator does not compare to an actual vehicle in terms of driver performance. It is possible that a similar technique could be used with other simulators (i.e., more "realistic," expensive simulators). Also, while high inter-rater reliability scores seem to indicate that the experimenters were judging driving performance based on the same criteria, automatically collecting driver performance measurements with the simulator's computer as compared to an instrumented vehicle may make comparisons between simulator and road more accurate. Finally, as recommended by A. Stein (personal communication, January, 1995), using complex maneuvers and turns with this particular simulator is discouraged; simulator sickness rates (reported or not) will be high as the number of turns increases.

In this study, the simulator route consisted of numerous turns and maneuvers. Out of the 14 people who completed all sessions, 6 (43%) complained of some uneasiness. Similarly, from the 11 participants who completed the debriefing interviews, 4 people (36%) said the simulator made them dizzy or nauseated. In addition, participants complained of problems with the graphics and with depth perception. On the other hand, 5 (45%) responded that the simulator was good/interesting and seemed real/useful. Also, many participants indicated that they felt driving behaviors could be learned or improved by using this simulator for looking and attention, traffic interaction, and for beginners and the young.

Limitations

Numerous limitations of this study exist and are described below. While this experimenter was interested in comparing road to simulated driving, this study was somewhat exploratory in nature, in that comparing road performance and simulator performance had not been done before. In other words, during the literature review, no research was found upon which to expand in reference to this particular simulator.

The number of participants who completed the protocol was low. Out of 19 potential participants, only 14 were able to complete the simulator portion of the study.

Similarly, the number of older subjects (4) was low. It seems that, while older participants are interested in the topic of driving and improving their safety, the lack of volunteers (particularly males) may be an indication of their resistance to "doing a study." This possibly stems from the fear of having their license removed, being told they "shouldn't be on the road," or other perceived threats to their independence, allowed by driving.

Additionally, another problem was related to trying to "squeeze too much" out of available resources. Thus, while not reported in this paper, a series of psycho-motor tests, a neurological exam, and driver history questionnaires were completed by most participants. With this, a typical session was over 3 hours and entailed much coordination of staff, schedules, and equipment; all in all, 4-5 people were needed to run each participant.

Finally, an important limitation should be kept in mind. A road to road or simulator to simulator correlation was not conducted. In other words, only 1 trial per environment was run. A better evaluation would have had each participant

do 2 or more trials per environment to attain more stable data. In addition, it is not known what the correlation for participants would have been had they had more trials for each environment. Although, the correlation between environments is .41, this may or may not be considered significant compared to the correlation between two evaluations in the same environment. Had information concerning road to road or simulator to simulator correlations been available, the relative strength of the obtained correlation may have been more interpretable.

Finally, before using a simulator in place of the road evaluation, normative data with this particular scoring technique needs to be collected. Only one participant scored in the "good performance" category; the remaining participants scored in the "fair performance" or the "needs evaluation/training" category. These were all "normal," licensed drivers!

Conclusion

The purpose of this study was to determine if a driving simulator can replace an on-road evaluation in the context of an Occupational Therapist (OT) Driver Assessment. The benefits of using a simulator to perform driver assessment include: 1) a more time- and cost-efficient method for evaluations (e.g., weather concerns would be eliminated), 2) the ability to evaluate drivers under complex conditions where failures are likely to occur, and 3) the safety of both the evaluator and driver would be improved.

With this in mind, the present study compared driver evaluations conducted on-road to that conducted in a medium-fidelity driving simulator. In doing so, differences between environments were discovered and previously discussed. With *this particular simulator*, the relationship between Road and

Simulator scores was only moderately positive. While sample size may have been a factor, it is believed that this is largely due to differences in fidelity and feedback between actual and simulated driving, coupled with the discomfort experienced in the simulator by a significant proportion of the participants, that caused a high drop-out rate. Thus, *as tested*, these results do not show strong promise for replacing on-road assessments *that are thirty minutes in length* with simulator assessment for OTs. In looking at the sub-components of the evaluation, some aspects of evaluation show a high correspondence and other aspects do not for explainable reasons. Continued research is proposed, addressing the differences between actual and simulated vehicle environments, perhaps by utilizing a similar evaluation technique with a variety of driving simulators (e.g., within a range of fidelity, costs, etc.). One may envision utilizing a different simulator that compensates for the lack of correspondence found in this study. Further, research is proposed addressing the establishment of OT evaluation techniques in conjunction with simulation. It is possible, as demonstrated by these results, that some aspects of evaluation may actually be better (e.g., more safely) evaluated with a simulator, while other aspects will optimally be evaluated on the road. On the other hand, it was also possible that using an evaluation form designed for on-road use accounted for some of the differences in driver performance scores. Perhaps scores of performance utilizing the simulator were biased in that cues (e.g., during braking) were substantially different for each condition. By understanding the differences and similarities between road and simulator driving, it may be possible to better use simulator evaluation in place of or as a complement to road evaluation.

It is known that OTs use specific criteria to measure driver performance on-road; investigation as to what criteria should be used to measure driver performance utilizing a simulator should be conducted. As demonstrated by this study, differences do exist between road and simulator, and compensation for these differences may be possible by an in-depth review of driver performance measurement criteria.

Licensing agencies and driver educators are looking for alternatives for current driving evaluation and training methods. A continued concern for highway safety, in combination with a societal reliance on the automobile as the most relied upon form of transportation, affords an opportunity for further driver performance research. If driving skills and behaviors can be accurately and reliably measured by using a simulator instead of or as a complement to an on-road evaluation, time, money, and lives could be saved. Clearly, more research needs to be conducted to determine the differences between actual and simulated vehicle environments and to refine OT evaluation techniques in conjunction with simulation. Further, to more successfully utilize *this particular simulator* (and perhaps other simulators) for driver performance evaluation, an in depth study is recommended to discover what components of simulated driving are most likely to induce simulator sickness or discomfort.

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APPENDIX A
REVIEW OF STUDY INSTRUCTIONS

(to be read aloud)

Thank you for deciding to participate in this study. I will now briefly describe for you what the session will consist of.

The purpose of the research is to investigate driving performance on the road and on a driving simulator.

First, a background information sheet and two questionnaires will be completed.

Second, we will evaluate abilities related to driving such as mobility and reaction time.

Third, you will drive on the driving simulator with an instructor for approximately thirty minutes after a brief orientation.

Fourth, you will drive on the road with an instructor for approximately thirty minutes after a brief orientation.

The entire session will take 3 hours and will be completed over one or more visits depending on your availability.

Appendix B
Driver Questionnaire

Driving Questionnaire

For the questions below, please FILL in the blanks or CIRCLE the word that best matches your answer. Please answer ALL questions; it is important that you give an answer for each question. Ask for help if you do not understand the instructions or any questions. Reminder: Your answers are CONFIDENTIAL.

1. Name: _____
2. How many miles per year do you drive? _____
3. How many days per week do you drive? _____
4. What part of the driving task concerns you most?
(e.g., changing lanes, highways, weather, trucks, pedestrians, other)
5. Do you avoid any of the following driving situations?:
  - a. Left turns across traffic Yes/No
  - b. Driving alone Yes/No
  - c. Driving at night Yes/No
  - d. Freeway driving Yes/No
  - e. Driving when raining Yes/No
  - f. other? (please describe)
6. What kinds of things do you do to make up for the skills you feel you may be weak in?
7. Do you take prescribed medications? Yes/No
If yes, has your physician or pharmacist
discussed their effects on driving? Yes/No

8. How many driving accidents have you been involved in over the last 3 years (list all accidents by date)_____
- 1.
  - 2.
  - 3.
  - 4.
9. Just about everyone gets a ticket now and then. How many moving violations have you been cited for over the last 3 years? _____
- What was the nature of these violations? (list all violations by type, e.g., speeding, running red light, etc.)
- 1.
  - 2.
  - 3.
10. I am concerned about my driving ability: Yes/No
11. I am a safe driver? Yes/No
- If no, why not?
12. Do you have normal or corrected (eye glasses, contacts, etc.) vision?
- _____
13. Do people ever honk at you? _____
- If yes, how frequently?
- Daily Weekly Monthly Yearly Rarely
14. How did you hear about this study? _____
15. At what year/age did you start driving? _____

Appendix C
Cognitive Failures Questionnaire

The following questions are about minor mistakes that everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to you in the last six months. Please circle the appropriate number.

	<u>Very Often</u>	<u>Quite Often</u>	<u>Very Occas.</u>	<u>Rarely</u>	<u>Never</u>
1. Do you read something and find you haven't been thinking about it and must read it again?	4	3	2	1	0
2. Do you find you forget why you went from one part of the house to the other?	4	3	2	1	0
3. Do you fail to notice signposts on the road?	4	3	2	1	0
4. Do you find you confuse right and left when giving directions?	4	3	2	1	0
5. Do you bump into people?	4	3	2	1	0
6. Do you find you forget whether you've turned off a light or a fire or locked the door?	4	3	2	1	0
7. Do you fail to listen to people's names when you are meeting them?	4	3	2	1	0
8. Do you say something and realize afterwards that it might be taken as insulting?	4	3	2	1	0
9. Do you fail to hear people speaking to you when you are doing something else?	4	3	2	1	0
10. Do you lose your temper and regret it?	4	3	2	1	0
11. Do you leave important letters unanswered for days?	4	3	2	1	0
12. Do you find you forgot which way to turn on a road you know well but rarely use?	4	3	2	1	0
13. Do you fail to see what you want in a supermarket (although it's there) ?	4	3	2	1	0
14. Do you find yourself suddenly wondering whether you've used a word correctly?	4	3	2	1	0
15. Do you have trouble making up your mind?	4	3	2	1	0

	<u>Very Often</u>	<u>Quite Often</u>	<u>Very Occas.</u>	<u>Rarely</u>	<u>Never</u>
16. Do you find you forget appointments?	4	3	2	1	0
17. Do you forget where you put something like a newspaper or a book?	4	3	2	1	0
18. Do you find you accidentally throw away the thing you want and keep what you meant to throw away - as in the example of throwing away the matchbox and putting the used match in your pocket?	4	3	2	1	0
19. Do you daydream when you ought to be listening to something?	4	3	2	1	0
20. Do you find you forget people's names?	4	3	2	1	0
21. Do you start doing one thing at home and get distracted into doing something else (unintentionally)?	4	3	2	1	0
22. Do you find you can't quite remember something although it's "on the tip of your tongue?"	4	3	2	1	0
23. Do you find you forget what you came to the shops to buy?	4	3	2	1	0
24. Do you drop things?	4	3	2	1	0
25. Do you find you can't think of anything to say?	4	3	2	1	0

Appendix D

Driver Results Form

Santa Clara Valley Medical Center
Occupational Therapy

Adaptive Driver Evaluation Program

ON-THE-ROAD DRIVING RESULTS:

Name _____

SS# _____

Date _____ / ____ / 95

Condition Road / Simulator

Instructor _____

Scorer _____

Client had: _____ Glasses

_____ License

BASIC DRIVING SKILLS

Results

Steering

- _____ 1. Maintains correct hand position for steering using steering device/both hands.
- _____ 2. Steers without weaving, touching or crossing over lane.
- _____ 3. Makes turns without cutting corners or too wide.
- _____ 4. Demonstrates appropriate smooth recovering of steering wheel on turns.
- _____ 5. Turns right/left from proper lane into proper lane.

Braking

- _____ 6. Stops with good anticipation and brakes car smoothly (no fast stops).
- _____ 7. Stops car completely at stop sign or red light (2 seconds).
- _____ 8. Stops so that position does not interfere with traffic or pedestrian, (i.e., behind limit line, can see rear tire or car ahead).
- _____ 9. Brakes quickly in reaction to hazard.

Accelerating

- _____ 10. Accelerates smoothly without jerky movement (no confusion between gas/ brake).
- _____ 11. Controls speed of car appropriately within posted speed limit, (i.e., too fast/too slow).
- _____ 12. Controls speed of car correctly approaching and leaving intersections.
- _____ 13. Controls speed of car appropriately in turns.
- _____ 14. Controls speed of car correctly during lane changes.
- _____ 15. Able to control vehicle speed up to 35/40 mph as traffic dictates.

=====

Scoring Key: 0 = Failed; 1 = Poor performance; 2 = Marginal performance;
3 = Satisfactory performance; 4 = Consistently good performance

Santa Clara Valley Medical Center
Occupational Therapy

Name _____

SS# _____

Adaptive Driver Evaluation Program

Date _____ / _____ /95

ON-THE-ROAD DRIVING RESULTS:

Condition Road / Simulator

Instructor _____

Scorer _____

Results

CAUTION/SAFETY AWARENESS

- _____ 16. Follow directions appropriately, i.e., verbal/written (road signs, speed limits).
 _____ 17. Demonstrates good eye lead time (12 seconds) for planned path of travel.
 _____ 18. Visually scans the environment for potential hazards.
 _____ 19. Allows "cushion" space between vehicles for safe braking and appropriate following distance, lane changes.
 _____ 20. Communicates with others by proper use of signals and eye contact.
 _____ 21. Uses mirrors appropriately for lane changes, braking and rear visual checks(every 8 seconds).
 _____ 22. Looks over appropriate shoulder for good visual awareness while backing up.
 _____ 23. Accepts and yields right-of-way appropriately to other vehicles and pedestrians.
 _____ 24. Approaches and leaves all intersections with proper cautions and visual checks (i.e., 2 way stop, 4 way stop, uncontrolled intersections).
 _____ 25. Demonstrates appropriate and timely lane change maneuvers (i.e., 3-step process or signal, mirror, blind spot).
 _____ 26. Physically maneuvers the vehicle correctly in response to changes in road conditions, traffic flow.
 _____ 27. Passes other vehicles properly.
 _____ 28. Allows other vehicles to pass when appropriate.
 _____ 29. Avoids objects, curbs, off-road shoulder in car maneuvers.

ADDITIONAL DRIVING SKILLS

- _____ 30. Backs up car with good control.
 _____ 31. Enters/exits parking space correctly.
 _____ 32. Performs U-turn with good control.
 _____ 33. Performs 3-point turn appropriately.

=====

Score (132) possible _____ Comments - Additional Findings _____

119-132 Good performance (90%) 0-6 hours. _____

99-118 Fair performance (75%) 6-12 hours. _____

80-98 Needs additional evaluation and/or training (60%) 12-25 hours. _____

below 80 Poor performance, should not drive _____

Driver's Training: _____ Emphasis on: _____

No Yes Recommend _____ hours _____

=====

Scoring Key: 0 = Failed; 1 = Poor performance; 2 = Marginal performance;
 3 = Satisfactory performance; 4 = Consistently good performance

Appendix E

Simulator Orienting Exercise Instructions

"4-Minute Orientation Exercise"

Simulator orienting exercise instructions

Once seated in the simulator:

To get used to how the simulator handles and what the scene looks like, we are going to go on an approximately 4 minutes of driving. We will start out in a quiet area and then move into some typical traffic scenes. This will give you a chance to get used to turning, stopping, and understanding the simulated traffic.

The participant will sit in the simulator and adjust the seat for optimal positioning. The instructor will orient the participant to the vehicle controls, including horn, turn signal level and indicator, gear shift level and indicator, speedometer, seat belt, parking brake, accelerator, brake, and mirror. Before starting the drive portion, the participant is told to put the seat belt on. Participants will be asked to return a demonstration of both setting turn signals and shifting gears ("Show me drive; show me reverse") to verify understanding prior to the test; the participant is also asked to point out the turn signal indicator and speedometer.

The accelerator and gas pedals are just like a real car. Start the vehicle and release the emergency brake. I will point out the differences and similarities between the simulator and driving a

car. For instance, notice the side mirror; this does not work, but may help you orient the vehicle. The rear-view mirror does work as you will soon see. We encourage you to drive as you normally would as though this was a real car.

For example, if you normally turn your head or body to check for traffic before making a lane change, go ahead and do that, even though this vehicle does not have a view all the way behind you. In other words, drive as if in your own car.

Please drive at your best driving behavior but feel free to ask any questions during this 4-minute segment. I will provide you with verbal instructions, such as "make a left turn here," or "make a u-turn." If no directions are given, proceed straight ahead. We can talk freely or pause at any time during this orientation. Ready? OK.

- 1) Now, move forward.
- 2) Remember, if no directions are given, proceed straight ahead. Always continue forward unless I say otherwise.
- 3) (At stop sign, at 6) OK, Good. Stay stopped here.

Notice the lane markings. The yellow lines show 2 lanes just like the real world. And the white limit line is here.

Move up a bit. Notice the front hood of the car here (pointing). This will help you orient when moving the car.

OK, make a left turn here.

- 4) Good. Notice that you should look into the left screen when you make a turn to more easily judge where the curb is.
(If no signal is given, remind the participant where the turn signal control is).
- 5) Speaking of curbs, let's run over the curb just to see what that's like.
Turn wheel so the vehicle goes over the curb.
That's right. And now, back onto the road.
OK, stop for a moment.
Notice how the steering wheel moves along with the "cha-chunk" sound when you hit the curb. Be sure to avoid those curbs. You will also notice some engine vibration in the seat.
- 6) Notice the lack of lane markings on this street. Like the real world, some streets do not have lane markings.
See that red traffic signal ahead? Notice the signal does not have a post but appears to be floating in mid air.
Also, notice the white limit line (pointing).
- 7) OK, let's continue.
(Before turning). Just like the real world, be sure to pull up to just behind the white limit line. Move up a bit so you can see traffic.
Speaking of traffic, here comes a vehicle now. Like the real world, there is a variety of vehicles in this simulation.
Make a right here.
- 8) You may want to look into the right screen when you make a turn to more easily judge where the curb is. OK, Good.

- 9) Notice the lane markings. This is a 4-lane road, with a center turning lane.
- 10) OK, let's get in the left lane.
Now, prepare for a U-turn at this light.
Treat the center passing lane (pointing) as an island; this is one thing that is different from the real world.
- 11) (when turning) Get a feel for the wheel. Good.
- 12) OK, here comes another vehicle toward you. When it passes by, notice what it looks like in your rearview mirror. This mirror only shows vehicles in it when a car passes you or is behind you.
Now, let's make a lane change to the left.
- 13) And here comes a vehicle behind you. (light turns green) Notice what it looks like when the car passes you on the right. Notice the car's brake lights and turn signal too.
(As approaching the red signal) OK make the next left. Notice there is a separate left-turn-only lane here (pointing).
- 14) Good.
- 15) OK, good. Make a lane change to the right and stop the car; we're done.
- 16) Great! Go ahead and secure the vehicle.

The experimenter will then have the participant exit the simulator and answer any questions. The experimenter will then ask the participant if it is too warm or cool in the room and adjust the fan and/or thermostat accordingly. Water and restroom are to be offered at this time as well.

Appendix F
Simulator Instructions

After questions are answered and participant is re-seated in the simulator:

The participant will adjust the seat for optimal positioning. Before starting the 30-minute drive portion, the participant is told to put the seat belt on.

Participants will be asked to return a demonstration of both setting turn signals and shifting gears ("Show me drive; show me reverse") to verify understanding prior to the test; the participant is also asked to point out the turn signal indicator and speedometer.

Then experimenter will say:

Now, we are going to go on an approximately 30-minutes of driving. We will start out in a quiet area and then will move into faster traffic. Again, please drive as you normally would as if you were in your own car and at your best driving behavior. Unlike the 4-minute warm-up, I cannot answer any questions during the route. If you would like to pause at any time let me know, otherwise we will stop every 10 minutes or so to take a brief break. Again, I will provide you with verbal instructions, such as "make a left turn here," or "make a u-turn." or hand signals. If no directions are given, proceed straight ahead.

Then:

Turn the ignition and release the emergency brake.

I am going to start you out with backing up the car around this corner
(pointing).

But first, we will slowly drive past the street on the right (pointing) which
you will back into.

Look to the right as you go by the street. Ready?

OK, move the car forward. Notice the edge of the curb.

00:05 OK, now stop the car.

OK, back the car into the street ...

00:25 and then turn left.

00:33.7 Make a right here.

00:41 Now make a right turn here (If participant asks which way to go, then
say "continue straight unless I say otherwise").

00:55 Take a left (at stop).

1:17 Now make a right turn (at stop).

1:52 Make a right (at 4, before hospital).
(continue through C and D)

2:43 Make your next left (signal at Main).

3:06 Take a left (signal at 6).

3:46 Take a left (at D, after green truck).

4:05 Make a right (at 4).

4:35 Please take the next left (at B).

5:05 Make a right (at 1).

5:25 Now I want you to make a 3-point turn around (at A & 1).

- 5:58 Make a left turn (at B).
- 6:20 Take a left here (at 3).
- 6:34 And a right here (at A).
- 6:50 Make a right (at 5).
- 7:10 Take a left (at B).
- 7:41 Make a right (stop sign at Wall).
(continue on Wall, past Main)
(continue on Wall, past I)
OK, pull over and stop.
- 9:29 PAUSE EXERCISE after Main
(after Burgundy Sedan on right)
OK, pull out and make a lane change to the left (before J)
(continue on Wall)
- 10:13 At the next signal, make a U turn (at N).
- 10:38 And get in the left lane.
- 12:12 Make your next left (at signal at Main).
- 12:58 Take a left (at signal at 4).
- 14:20 Make left here (at I).
- 14:48 Take a left (at 6).
- 15:08 Make a left (at H).
- 15:42 Take a right (at 3).
OK, pull to the right and stop.
- 15:55 PAUSE EXERCISE
OK, let's continue

- 16:12 Make your next left (at F).
(Past light)
- 16:25 Now make your next right (lane change).
- 16:43 And another right (at signal at Main).
(continue on Main)
- 17:14 Now make a left lane change.
- 18:50 Now, see that sign on the left?
- 18:53 Make a 3-point turn now before the signal (just past fire station).
- 19:16 And now make a right into this building.
- 19:25 Park vehicle in the left stall.
And secure the car as if you were getting out.
- 19:50 OK, when ready, back the car out and turn around.
- 20:02 Make a right here (at Main).
- 20:07 And your next right (at signal at 12).
- 20:18 Make a left (at D).
- 22:28 Make a right here (at 1).
- 22:43 Another right here (at C).
- 23:05 And a right here (at 3).
- 23:31 Make a right (at Main).
- 23:56 Another right at the signal (at 2).
- 24:10 Make a right (at D).
- 24:12 Park on the right side across from that white van (after D).
- 24:20 Secure the vehicle.
- 24:33 OK, you're done.

Appendix G
On-Road Instructions

Once in vehicle:

The participant will be given the car keys to open the door. He or she will sit in the vehicle and adjust the seat for optimal positioning. From outside the vehicle the instructor will orient the participant to the vehicle controls, including horn, turn signal level and indicator, gear shift level and indicator, speedometer, seat belt, parking brake, accelerator, brake, and mirrors. Before starting the drive portion, the subject is told to put the seat belt on. Participants will be asked to return a demonstration of both setting turn signals and shifting gears ("Show me drive; show me reverse") to verify understanding prior to the test; the participant is also asked to point out the turn signal indicator and speedometer.

Then:

We are going to go on an approximately 30-minutes of driving. We will start out in a quiet parking lot area and then will move into faster traffic. This will give you a chance to first get used to the car. Please drive at your best driving behavior. I will provide you with verbal instructions, such as "make a left turn here," or "make a u-turn" or hand signals. If no directions are given, proceed straight ahead. I will be able to give you feedback on your driving performance after the test, but not during.

Start the vehicle and release the emergency brake.

I want you to back up the car (out of the parking stall) so that the rear end is close to the overhang (of the hospital building).

Now, make a left turn (through parking lot).

Make a right here.

Now make a left turn.

Make a right turn here (Stop sign at Enborg). (If participant asks which way to go, then OT says "continue straight unless I say otherwise.") Take a right (on Thorton, 3-way stop).

Make a left at Moorpark (a green-ball signal, uncontrolled left turn).

(If participant is now in right lane then, "get in the left lane.")

Make a left at this light.

Take your next left (at Ori)

(after Stop Sign)

Follow around to the right (at S. Daniel Way)

(after Neal)

After the next street, I want you to turn the car around (after Williams)

Make a left here.

Take another left (S. Genevieve Lane).

Take a right (at Clifton).

Please make another right (on Greenbrier).

Make a left (after 1 street to Van Sansul).

Take your next right (onto Winchester).

Please make a lane change to the left (just past Riddle.)

At the next light make a U turn (at Moorpark).

Make a lane change (to the right).

Make a lane change (to the left).

At the next signal make a left (at Hamilton).

(before 17)

Please prepare for the next left turn.

(Make a lane change to the left.)

Please make this left here from the left-most lane (at Bascom).

(Stay in the left lane.)

After the next street make a left turn into the parking lot.

(into the bakery parking lot, after Downing)

Please turn into this parking lot and park the car.

Please secure the car as if you were leaving the vehicle.

OK, now start up the car and back up out of stall.

Please make a right turn (onto Bascom).

Make a lane change (to the left).

Make a U turn at the next street (at Downing - [or Stokes]).

Please make a lane change (to the left).

Turn left at the next signal (at Fruitdale).

Turn right into the Hospital parking lot.

Make a right.

Please make a left here.

And another left.

Please park and secure the car in that stall ahead of us.

OK, we're done.

Appendix H
Additional Participant Information

Medication. Of the entire pool of participants, 12/19 (63%) did not report taking medications. 7/19 (37%), reported taking some sort of medications regularly. Among these participants, 16 medications or 2.29 medications per person (s.d. = 1.11), were being taken. Out of the 14 participants who completed all sessions, 11/14 (79%) did not report taking medications. 3/14 (21%) reported taking some sort of medications. Of the participants who did not complete the simulator session, 3/5 (60%) reported taking medications.

The sixteen medications included Sinemet CR, Eldepryl, Synthroid, allergy medicine, Amoxicillin, Hormones, Prozac, Inderal, Isordil, Lysinopril, Ecotrin, Thyroid, Timoptic eye drops, Estrogen, Procardia, and Aspirin.

Corrective lenses. Of the entire pool of participants, the number of participants who did not wear corrective lenses was 7/19 (37%). The number that wore corrective lenses was 12/19 (63%). Of those participants that wore corrective lenses, 5/12 (42%) did so for distance, 6/12 (50%) wore bifocals, 2/12 (17%) wore trifocals, and 1/12 (8%) wore contact lenses. Out of the 14 participants who completed all sessions, 6/14 (43%) did not wear corrective lenses. 8/14 (57%) did wear corrective lenses. Of those participants who did wear corrective lenses and completed all sessions, 3/14 (21%) did so for distance, 3/14 (21%) wore bifocals, 2/14 (14%) wore trifocals, and 1/14 (7%) wore contact lenses. Of the participants who did not complete the simulator session, 4/5 (80%) wore corrective lenses and 1/5 (20%) did not. Of those that wore corrective lenses, 1/4 (25%) did so for distance, and 3/4 (75%) wore bifocals.

Education. Of the total number of participants, the average level of education was 15 years (s.d. = 1.97).

Appendix I
Interview Questions

Name: _____

Participant #: _____

Date: ____/____/95

1. Do you have any comments about your experience today in general?
2. What did you like most about the simulator?
3. What did you like least about the simulator?
4. Did you feel any uneasiness as you drove the simulator?
5. Did the maneuvers seem realistic?
6. Do you feel that driving behaviors could be learned or improved by using such a device?
7. Other comments?