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BASIC SCIENCE

The effect of shoulder immobilization on driving performance

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Background: The purpose of this study was to evaluate the effect of sling immobilization on driving performance with use of a driving simulator.
Methods: This is a prospective trial with a cohort of 21 healthy volunteers comparing their driving ability with and without sling immobilization on their dominant (driving) extremity. Multiple variables, including number of collisions, off-road excursions, and centerline crossings, were measured with a validated driving simulator. Trials were separated by 2 weeks to control for "adaptations" to the simulator. Statistical significance was found in collisions between sling and no-sling tests.
Results: The total number of collisions for trial 1 (no sling) was 36 (mean, 1.7 ± 1.2) compared with 73 (3.7 ± 1.6) ($P < .01$) for trial 2 (sling immobilization). Approximately 70% of participants with upper extremity immobilization were involved in ≥3 collisions; approximately 70% of no-sling participants were involved in ≤2 collisions. There was no statistically significant difference between groups with respect to overall vehicle road position and control.
Conclusion: Sling immobilization of the dominant driving arm results in a decrease in driving performance and safety with respect to the number of collisions in a simulated driving circuit ($P < .01$). There were no significant differences in driving parameters that are indicative of overall vehicle position and control. The decrease in driving performance with respect to the number of collisions is likely to be related to the effect the immobilized arm has on effectively performing evasive maneuvers during hazardous driving conditions.
Level of evidence: Basic Science, Kinesiology.

Keywords: Driving; driving safety; driving simulator; driving guidelines; guidelines; shoulder immobilization; upper extremity; sling

Automobile accidents are a significant cause of death and injury in the United States, with more than 35,000 people killed in more than 10 million accidents every year.[27] Human error is a primary cause in 57% and a contributing factor in more than 90% of all accidents.[30] A review of the literature conducted by the National Highway Traffic Safety Administration (NHTSA) suggested that patients with functional motor impairments and musculoskeletal abnormalities have a much greater risk for at-fault crashes.[5]

Although there is a paucity of literature on the overall contribution of medically related causes to the number of

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motor vehicle accidents, physicians have a medicolegal responsibility to assess potential functional impairments of patients with respect to driving. Common questions asked by patients after treatment of upper extremity conditions and injuries include When can I drive? and Can I drive in a sling? As physicians, we should have evidence-based information that allows us to answer these commonly asked questions.

Driving is a multisystem task that requires cognitive coordination of a variety of complex and coordinated muscle actions. The safe operation of a motor vehicle requires the driver to have adequate range of motion of the extremities to perform steering, braking, reversing, and maneuvering of the vehicle. Immobilization of either the upper or lower extremities is frequently part of the management of a variety of orthopedic conditions. Patients frequently inquire about their functional capacity to drive and often request time frames for their ability to safely return to driving. However, there is a relative paucity of scientific data regarding fitness to drive in patients being treated for orthopedic conditions such that consistent recommendations from health care providers are not available. The importance of establishing evidence-based guidelines is critical because the term *fitness to drive* represents a multifaceted issue with medical, legal, and financial implications.

The development of driving simulators allowed studies to be performed to examine the effect of orthopedic injuries and their treatments on the ability to drive safely.[6-8,11,13,19,24,29] Studies examining the effect of ankle fracture fixation,[7] total hip arthroplasty,[19] total knee arthroplasty,[29] and knee arthroscopy[11] on driving performance have helped define guidelines for return to driving after these procedures. Research on the effect of immobilization on driving safety has primarily focused on the lower extremity,[6,7,14,26,31] with brake reaction time as the primary outcome. There have been few studies examining the effect of upper extremity immobilization on driving performance, with the majority of research focusing on above- and below-the-elbow casts and splints.[4,9,12,14,15]

To our knowledge, there has been no study investigating the effect of shoulder immobilization on driving safety. Using a validated computerized driving simulator, this study sought to determine the effect of dominant arm sling immobilization on driving performance with a driving simulator. Our hypothesis was that sling immobilization of the dominant driving arm would result in inferior driving performance compared with normal driving conditions.

Methods

This study used a driving simulator to reproduce actual driving conditions in an automatic transmission vehicle (Fig. 1, *A*). To assess the change in driving performance, a previously established testing model was employed.[6,7] The software and hardware simulation setup used has been previously validated in numerous studies.[18,20,22,25,35] Specifically, automobile components of the driving simulator included brake and accelerator pedals connected to a brake cylinder and force transducer, an adjustable steering column, and an adjustable car seat. The pedal assembly is connected to an analog-to-digital converter that transmits positional information to the computer. An LCD panel monitor (Dell, Round Rock, TX, USA) was placed at eye level. Surround speakers (Dell) were used to produce road sounds and to provide instructions to the subject. LabVIEW software (National Instruments, Austin, TX, USA) was used to collect and to display data by an analog or digital board (AT-EIO-64; National Instruments) with a sampling rate of 1000 Hz from the accelerator and brake pedals. Windows STISIM Drive V2.0 software (Systems Technology, Hawthorne, CA, USA) was used to design customized circuits for acclimatizing subjects to the software as well as for testing subjects in simulated real-world driving conditions (Fig. 1, *B*).

Simulated driving environment

Subjects underwent a training circuit before testing by driving freely on a simulation circuit that allowed them to become comfortable within the driving environment as well as to gauge how responsive the simulator was to their movements. All patients were able to easily adjust to the driving interface, and a learning curve was not appreciated. During the training circuit, the participants used both hands while driving. On completion of the training circuit, a braking reaction circuit (BRC) was conducted. Break reaction time was calculated by the average of 3 reaction times (full depression of the brake) to sudden stop signals on the display. This reaction time was used to calibrate the simulation course for each volunteer to control for variability between trials in eye-to-foot response time. Once calibrated, a simulated driving circuit (SDC) lasting approximately 8 minutes was then conducted. The SDC was designed to represent a suburban environment, recreating standard turns, traffic intersections, pedestrian crosswalks, and several hazards routinely encountered during driving situations.

Custom-designed driving circuit

The simulated speeds when approaching the hazards were computer controlled to allow uniform analysis, that is, each subject approached road hazards at the same speed. With the patient-specific eye-to-foot response time from the BRC and standardized speeds in scenarios requiring evasive maneuvering, each specific trial was calibrated to minimize confounding variables to amplify any potential effects on driving performance that are directly related to complex upper extremity movements. Patients were also instructed to stay below the indicated speed limit. In the event that subjects exceeded this limit, a computer-generated auditory warning was issued. The net effect of the subject-specific customization of the simulated circuits allows elimination of confounding variables such as variability in speed and poor braking to directly investigate the impact of shoulder immobilization on driving performance.

Healthy volunteers and sling immobilization

After informed consent, 21 healthy volunteers were tested in 2 trials. Inclusion criteria included age between 20 and 70 years,