BASIC SCIENCE

The effect of shoulder immobilization on driving performance

Saqib Hasan, MD, Edward Chay, MD, Abiola Atanda, MD, Alan W. McGee Jr, MD, Laith M. Jazrawi, MD*, Joseph D. Zuckerman, MD

Department of Orthopaedic Surgery, New York University Hospital for Joint Diseases, New York, NY, USA

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.

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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. Human error is a primary cause in 57% and a contributing factor in more than 90% of all accidents. 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.

Although there is a paucity of literature on the overall contribution of medically related causes to the number of accidents.
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. Studies examining the effect of ankle fracture fixation, total hip arthroplasty, total knee arthroplasty, and knee arthroscopy 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 with 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.

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. The software and hardware simulation setup used has been previously validated in numerous studies. 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,
absence of systemic disease or previous extremity surgery that could affect driving ability, no neurologic conditions, possession of a valid driver’s license, and no history of shoulder or upper extremity dysfunction. Each volunteer’s driving experience (number of years) and total number of previous car accidents were recorded. Patients were surveyed concerning which arm they felt they used predominantly while driving; this information was used in selecting which arm would be immobilized in the sling (S) trial. Given the survey responses gauging the patient’s driving arm preference, immobilization of the nondominant driving arm was not investigated as it was thought it would not provide valuable data because the nondominant driving arm was self-reported to not be typically used during everyday driving. Each patient was initially tested in the BRC to allow standardized calibration of the SDC, as previously described. The no-sling (NS) trial consisted of driving the SDC with no immobilization of extremities; during the NS trial, patients were instructed to drive with both hands. The S trial consisted of driving with the self-reported dominant driving arm immobilized in an UltraSling III (DonJoy, Vista, CA, USA), which is a simple shoulder sling without any attachment to the body other than the strap around the neck.

The arm was immobilized with the elbow in 90° of flexion, allowing active motion of the arm within the sling; however, patients were instructed to not use the immobilized extremity while driving in all circuits. Participants were randomized with respect to the temporal order of each trial, with a 2-week gap between trials to minimize any potential learning bias.

Data analysis

By use of a custom MATLAB (MathWorks, Meudon, France) program, the real-time data for each trial were converted to the number of off-road excursions, number of collisions, minimal lateral position, maximum lateral position, maximum steering angle, and closest object. Briefly, off-road excursions are defined as computer-recorded events whereby the subject exceeded the computerized boundaries of the SDC. The number of collisions was the total number of simulated on-road hazards (i.e., approaching car, pedestrian, barrels) that were struck. The minimal lateral position is the closest distance, in feet, that the calculated center of the car came to the left side of the road throughout the course. The maximal lateral distance is the farthest that the calculated center of the car was from the left side of the road (the center of the road was 7.5 feet from the left side of the road). Maximum steering angle was the largest turn that the driver made, measured in radians, while traveling at a computer-controlled speed through each turn or when avoiding collisions. One-way analysis of variance was used to determine whether differences in driving parameters existed between trials (intratrial analysis). Unpaired t test was used for intergroup analysis. Statistical analysis was performed with SPSS version 17 (Chicago, IL, USA).

Results

Twenty-one participants met the inclusion criteria and participated in the study, consisting of 11 men and 10 women with a mean age of 26 ± 3 years (range, 21-36 years) and mean driving experience of 10 ± 7 years. A post hoc power analysis demonstrated that 9 patients per group were necessary to detect differences in collisions between the 2 cohorts with 80% power.

The participants reported 0 to 3 lifetime accidents, with a mean of 0.88 accident. Eight of the participants were left-hand dominant, 13 participants were right-hand dominant, and 0 participants reported “no preference.”

The S trial had 3.7 collisions compared with 1.7 collisions in the NS trial (P < .01) (Fig. 2). The incidence of off-road excursions was similar between the S and NS groups, 0.6 vs 0.5 (P = .77).

There were no significant differences in driving performance parameters as measured by minimum distance (feet) from road edge (S trial, 7.4; NS trial, 7.8; P = .65), maximum steering angle (radians) (S trial, 15.2; NS trial, 15.2; P = .25), and minimum distance to collision (S trial, 16.4; NS trial, 20.6; P = 0.13) when encountering a hazard in the S vs NS groups (Fig. 3). No significant difference was found in minimum distance (feet) from road edge (S trial, 3.3; NS trial, 3.2; P = 0.59) or maximum steering angle (S trial, 5.5; NS trial, 4.8; P = .62) when performing turns in the S vs NS groups (Fig. 4).

Discussion

The main outcome measures that were used in our investigation of driving performance with the dominant extremity
in a sling can be divided into 2 types of parameters: those testing routine driving ability and those simulating a worst-case scenario whereby evasive maneuvering is required to avoid a road hazard.

Variables such as vehicle position, steering rate and acceleration, and distance to road objects if no collision ensued measure routine driving performance in the context of vehicle control and position on the road. Because these parameters were recorded at all points in the trial, including all turns, they reliably test performance under nonhazardous conditions and as a result can identify any perceived effects of shoulder immobilization on day-to-day “routine” driving.

Our primary parameter for assessing worst-case scenario driving was the number of collisions recorded when subjects were required to perform an evasive maneuver to avoid a road hazard. Because the SDC was calibrated to each subject’s brake reaction time from the BRC and all speeds when approaching a driving hazard were standardized, confounding variables were minimized to identify the effects on driving performance that are directly related to complex movements that require the use of the upper extremity.

Our results showed no significant differences between immobilization and nonimmobilization of the self-reported dominant driving arm on analysis of routine driving ability. These variables represent normal everyday driving as they reflect acceptable vehicle position on the road at suburban speeds and turns. However, our results did demonstrate that driving with the dominant arm immobilized resulted in a statistically significant increase in the number of collisions compared with no immobilization. The number of collisions for each subject during normal driving without immobilization represents baseline operator-dependent limitations of the driving simulator hardware and software. These operator-dependent “errors” serve to provide a baseline of driving performance, given the limitations of the simulated nature of the study, and allow comparison of driving performance when the subject’s shoulders are immobilized. The collisions were also during more evasive maneuvers and not during routine driving, which by itself can result in a collision with 2-handed driving. The number of collisions nearly doubles in comparing the S trial with the NS trial. These results support the conclusion that sling immobilization impedes the driver’s ability to effectively perform evasive maneuvers when faced with a driving hazard.

Studies examining the impact of immobilization of lower extremities on driving safety are numerous, in part because of the relative ease...
of ascertaining study end points, such as brake reaction time, followed by extrapolation to the potential effect on driving safety. In contrast, investigation of the consequences of immobilization of the upper extremity is a greater challenge. Potential difficulties in research design are multifactorial and range from the considerable inconsistency among drivers with respect to upper extremity use while driving to factors such as the variability inherent in the cognitive and motor coordination of maneuvering a vehicle. However, the primary limiting factor is the development of measurable study end points that have a predictive value in the context of driving safety.

There have been 2 studies that have used objective measurements to examine the effect of upper extremity immobilization on driving safety. However, these studies have focused on immobilization with above-the-elbow and below-the-elbow splints. One study used a driving simulator in 8 healthy volunteers to evaluate the effect of wrist immobilization with a below-the-elbow splint. The authors measured variables that included position, steering rate, accelerator activity, proximity to on-road hazards, and total number of collisions. Results of the computer-simulated driving trials showed that the great majority of variables measured did not show any significant differences between the immobilized and nonimmobilized groups. However, when data specific to driving conditions in which the driver was faced with a road hazard were analyzed, significant deviations in vehicle trajectory, vehicle position, accelerator activity, and distance to on-road objects were observed in the group that had the dominant wrist immobilized. The authors concluded that immobilization of the dominant wrist with below-the-elbow splints resulted in unsafe driving practices when faced with hazardous driving conditions.

A more recent study investigated the effect of immobilization with thumb spica splints on driving performance using a standardized driving performance course for the training of emergency personnel. Thirty-six healthy officers-in-training were scored by a standardized protocol during a series of trials in which the volunteers were assigned to sequentially wear above-the-elbow and below-the-elbow thumb spica splints on both left and right extremities. The authors concluded that all forms of immobilization showed a trend toward worse driving performance compared with no immobilization. However, left below-the-elbow and left above-the-elbow thumb spica splints resulted in the greatest decrease in performance, which the authors attributed to visual and spatial constraints inherent with a left-sided driver seat. Whereas the scoring system and course used in this study sought to create reliable end points for extrapolating driving safety, certain difficult driving maneuvers, such as reversing, parking, and 3-point turns, may have amplified the actual effect of driving with upper extremity immobilization. The goal of our study was to build on previous research on upper extremity immobilization by evaluating the impact of sling immobilization of the dominant arm on driving performance.

A limitation with the aforementioned studies as well as with our study is the lack of an externally validated model. To our knowledge, there is no well-defined, validated model with measurable end points that can truly evaluate upper extremity function in the context of driving performance. However, our position has been that through the use of a validated driving simulator, which has been used in a variety of studies both in the medical and in the orthopedic literature, we have been able to create a customized driving circuit that directly tests upper extremity function in the context of driving by minimizing confounding variables such as variability in speed and braking, particularly in worst-case scenario situations that require coordinated evasive maneuvering.

In the United States, a policy statement issued by the Council on Ethical and Judicial Affairs of the American Medical Association describes the central responsibility of physicians to assess physical and mental impairments that might adversely affect driving. The duty of physicians to educate their patients is further reiterated in the guidelines for assessing and counseling older drivers established by the NHTSA.

Whereas guidelines for driving after anterior cruciate ligament reconstruction, total knee replacement, and total hip replacement have been substantiated by scientific studies, many of the NHTSA recommendations are not evidence based and are not reflective of the current literature involving fitness to drive in the context of orthopedic injuries and treatment. Furthermore, neither the American Academy of Orthopaedic Surgeons nor any other orthopedic society has endorsed recommendations or practice guidelines that address safety to drive in the context of musculoskeletal injury. Whereas the NHTSA recommendation is to avoid driving with any splint or immobilization device that may interfere with driving, studies have shown that patients often continue to drive despite extremity immobilization. The prevalence of noncompliance clearly indicates the need for evidence-based recommendations for patients whose care involves the use of temporary immobilization devices.

Our data indicate that sling immobilization does impede the driver’s ability to effectively perform evasive maneuvers. This may be a pure “motor” effect in which the use of a single upper extremity is not sufficient to properly react to a road hazard. Alternatively, there may also be a cognitive component as proposed in previous studies in which immobilization of the dominant driving arm was associated with an altered processing of spatial information and decision making, resulting in impairment in a driver’s ability to efficiently react and to control the vehicle as would be done in “normal” driving with the use of both upper extremities.

Although our study has important implications for driving recommendations with sling immobilization, there are several limitations. As mentioned previously, in both
the present study and previous studies, it remains difficult to isolate study end points that can objectively and directly measure the effect of upper extremity immobilization on driving performance. Our study sought to overcome this complex issue in several ways. First, we used a validated driving simulator that has been used in numerous studies investigating the effect of different medical conditions on driving performance. To further limit the variability between drivers with respect to reacting to road hazards, the course was customized to each specific driver, taking into account individual brake reaction time and speed of the vehicle approaching the road hazard. By creating controlled hazardous conditions in which the collision depends on effectively performing an evasive maneuver, we are more confident that our results can be extrapolated to certain aspects of actual driving.

Second, whereas the circuits created for this study were representative of actual circumstances, there are aspects of driving that were not able to test. Complicated maneuvers such as moving the car in reverse, parallel parking, and 3-point turns were not assessed because of limitations of our driving simulator. However, we think that these more complex driving maneuvers—more complex than the maneuvers we tested—would also be adversely affected by upper extremity immobilization.

Another potential limitation of this study is the study group used. It may not necessarily be representative of the general population, with a mean age of 26 ± 3 years and mean driving experience of 10 ± 7 years. It is possible that this younger population with fewer years of driving experience may not have displayed evasive maneuvering that is typical for the general population. However, it is also possible that the effects of immobilization may be more profound on older individuals who are more likely to have comorbid conditions and to use medications. Given our results, an important distinction must be made with regard to driving safety in the context of patients with permanent disabilities such as brachial plexus injuries or amputees. The Association for Driver Rehabilitation Specialists provides support to patients with disabilities through comprehensive evaluations to assess driving capacity and to identify adaptive equipment to allow patients to safely return to driving.

In actual clinical situations, patients requiring use of a shoulder immobilizer may also be using analgesics, which can adversely affect driving performance. This variable was not included in our study but will be assessed in planned studies of patients who recently underwent shoulder surgery.

Conclusions

Whereas a surgeon may be capable of determining when an injured limb may regain the functionality to resume driving, he or she may not be qualified to make a final determination of overall driving ability, given the multisystem requirements that the task of driving demands. To address patient safety and medicolegal concerns, state licensing authorities may be of limited assistance. Only 38 states have established medical advisory boards that can address return-to-driving issues on a case-by-case basis. However, the composition of members, guidelines, and responsibilities vary by the state. Even though a brief office visit may not facilitate a comprehensive assessment of a patient’s ability to safely drive, in 19 states, authorities or medical advisory boards still base their decisions on a patient’s fitness to drive on medical certification by a treating physician.

This study is the first that evaluates driving safety in the context of the commonly encountered situation in which sling immobilization of an upper extremity is required. Our results demonstrate that although driving with the dominant arm immobilized in a sling may not adversely affect standard driving conditions, it does adversely affect the ability to effectively perform evasive maneuvers when facing hazardous driving conditions. Given the significant medical, legal, and financial ramifications involved, it is our opinion that driving with the dominant driving arm immobilized in a sling is unsafe and as such cannot be recommended.

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References


