Effects of Upper Extremity Immobilization and Use of a Spinner Knob on Vehicle Steering

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Abstract

Background: A person's ability to safely drive while immobilized is not well defined. Steering ability with a spinner knob during immobilization is unknown. The goal of this study is to further clarify the effect of immobilization on steering reaction time and accuracy with and without a steering wheel spinner knob. **Methods:** Twenty participants were enrolled in this crossover trial using a driving simulator with an automatic transmission. Five conditions were tested in a counterbalanced order. Steering reaction time and accuracy (number of errors on a dynamic steering task at 2 difficulty levels) were measured. Participants were allowed to steer with the immobilized extremity. **Results:** No significant differences in reaction time were observed between any conditions. Both immobilized conditions and difficulty level of the steering task led to diminished accuracy compared with controls, resulting in significantly more errors. The use of a spinner knob significantly improved the accuracy for the condition with the sugar-tong splint during the easier steering task, but this improvement was not observed in the harder steering task. There were no differences between conditions based on gender or observed use of the immobilized arm. **Conclusions:** Immobilization had a negative effect on steering accuracy for both the wrist splint and the sugar-tong splint condition, which may negatively impact driving ability of immobilized patients. Immobilization, regardless of spinner knob use, did not significantly impact steering reaction time. The steering wheel spinner knob did not consistently improve accuracy, and further study is needed to determine its utility.

Keywords: upper extremity, steering, spinner knob, immobilization, driving simulator, cast, splint

Introduction

The use of upper extremity immobilization is common in both primary care and orthopedic practices. A person's ability to drive a car safely while immobilized is not well defined. A majority of orthopedic surgeons (76%) did not have a consistent return-to-driving policy,³ and there is not agreement on whether a person with an upper extremity fracture treated in a cast should be allowed to drive.¹⁵ There are no formal guidelines from orthopedic societies to help physicians in determining the ability to return to drive,¹⁶ and it is common for patients to drive, despite the physician's recommendation to abstain from driving.^{11,12}

Physicians likely recommend limiting driving for a variety of reasons. A patient's ability to steer a vehicle while immobilized is not well known and may pose a risk to both patient and society. Conceivable medicolegal risks to the physician may pressure physicians to practice "defensive" medicine.³ However, restriction of driving unnecessarily can have significant implications for patients. Patients who sustained a musculoskeletal injury reported that the inability to drive

created some degree of difficulty for 73% surveyed, of which 42% found this to be a major difficulty.³ Patients may feel trapped at home. The reliance on family/friends for transportation or the reliance on public transportation can have time and/or financial strains for both the patient and/or family.

Driving is a highly complex task involving all 4 extremities, the sensory and motor system, and higher-level nervous system functions like analysis of risk and decision making. Any interruption or slowing in the ability to process one's surroundings through visual or auditory sensation to execution of an action could put the driver and others at risk. Upper extremity immobilization could affect driving ability because of the inhibition of musculoskeletal execution.

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People with lower extremity loss or deficit may use hand controls to drive. The hand controls operate the pedals, while a spinner knob attached to the steering wheel allows for 1-handed operation. While hand controls vary widely in price and complexity, spinner knobs are generally inexpensive and readily available off the shelf. We are unaware of any state laws governing the use of a spinner knob. However, a local Certified Driving Rehabilitation Specialist, an occupational therapist with specialized training in driving rehabilitation for a broad range of medical conditions, would be familiar with local laws.¹ Certified Driving Rehabilitation Specialists serve as the current gold standard for determining driving fitness, but their evaluation is not practical for most short-term impairments.

The effects of upper extremity immobilization on steering reaction time and accuracy have not been fully assessed. Steering ability with a spinner knob during immobilization is unknown. The goal of this study is to further clarify the effect of immobilization on steering reaction time and accuracy with and without a steering wheel spinner knob. The primary hypothesis was uninjured participants with upper extremity immobilization would have worse vehicle steering reaction time and accuracy compared with no immobilization. The secondary hypothesis was participants with upper extremity immobilization would have improved vehicle steering reaction time and accuracy with use of a steering wheel spinner knob.

Materials and Methods

The institutional review board approved this study. A total of 20 healthy individuals (10 male and 10 female) without any injury or intervention were recruited for the study. Inclusion criteria were the following: right-handed, at least 18 years of age, a valid driver's license, and at least 20/40 vision with or without corrective lenses. Participants with an upper extremity deficit that inhibited full range of motion were excluded. Baseline information was collected for each participant (Table 1).

The study design was a 5×5 crossover trial. Participants were tested on a series of 5 immobilization conditions over the course of several hours in a single day. Each immobilization condition included 3 driving simulator test scenarios, resulting in a total of 15 tests per participant. To minimize the effect of participants' learning error (carryover effect), the order of the 5 test conditions was counterbalanced in blocks of 10. Computer randomization was used to assign participant numbers, and study packets were sealed in identical, opaque study envelopes. The time it took to complete each series of tests and change splints served as the washout period for each individual test (approximately 20 minutes). After obtaining informed consent, participants were briefly introduced to the simulator.

Table 1. Participant Demographics.

	Mean	SD
Age, y	23	2.7
Years driving	5.1	2.3
Video game play, hr/d	0.8	0.8
History of driving immobilized	2 (1 splint, 1 cast)	
History of use of a steering wheel spinner knob	4	

Description of the Simulator

Participants completed all testing in a DriveSafety DS-250 driving simulator (Figure 1). The simulator was designed for clinical settings.⁵ The driving simulator consists of the partial cab of a first-generation Ford Focus that is linked to 3 adjustable, side-by-side video monitors. The cab features an adjustable aftermarket automotive seat with 2 armrests, seatbelt, center console, and dashboard. The steering provides dynamic electric torque feedback, and steering wheel sensors output continuous data of the steering wheel position at 60 Hz.

Description of Test Conditions

Five immobilization conditions were evaluated:

- no immobilization on either arm (control);
- right arm immobilized with an off-the-shelf removable wrist splint;
- right arm immobilized with an off-the-shelf removable wrist splint, left hand using a steering wheel spinner knob;
- right arm immobilized with an above elbow sugar-tong splint;
- right arm immobilized with an above elbow sugar-tong splint, left hand using a steering wheel spinner knob.

The off-the-shelf removable wrist splint was sized to each participant and verified to restrict wrist flexion and extension. During wrist splint conditions, participants were given the following instructions:

“Imagine you are now an injured person with a wrist sprain. The removable wrist splint is primarily for comfort and protection of your injury. Full, unrestricted use of your extremity in the wrist splint is allowed to your comfort level.”

The sugar-tong splint was formed from 3-in padded fiberglass splint material (ScotchCast, 3M Healthcare, St. Paul, MN) and an ace wrap. The sugar-tong splint began at the

Figure 1. DriveSafety DS-250 driving simulator.

distal palmar crease, extended around the posterior side of the elbow, and ended at the metacarpal heads on the dorsal hand. During the sugar-tong splint conditions, participants were given the following instructions:

“Imagine you are now an injured person with a broken wrist. The Sugar-Tong Splint is holding your fractured wrist bones in the proper place. It is okay to use your right hand for light grasping tasks (like eating or personal care), but it is advised that you do not lift any heavy objects. Moving your arm within the confines of the splint is okay.”

For the steering wheel spinner knob conditions, the knob (Spin Master A600, Sure Grip-HVL, Howell Ventures Ltd, Upper Kingsclear, New Brunswick, Canada) was attached to the steering wheel in the 8-o’clock position. The participants were given the following instructions:

“The spinner knob is an assistive device for one-handed steering. In these sets of tests that include the spinner knob, you **MUST** use it for steering with your **LEFT** hand.”

Participants were allowed to determine how much use each arm contributed to the steering tasks, and use of the

immobilized arm was estimated by direct observation by the simulator operator and quantified as a percentile during testing. Since the use was subjective, the percent use was broken into quartiles. In the control condition without immobilization, the percentile of 2-handed steering was quantified. If participants asked for clarification whether to use their immobilized arm during any of the test conditions, they were read the instructions again.

Description of Test Scenarios

The 3 test scenarios for each condition were Reaction Timer Steering, Steering Chase–Level 2, and Steering Chase–Level 3 (Tables 2 and 3). Steering Chase scenarios tested steering accuracy at 2 difficulty levels. Participants were instructed to focus on accuracy. Each participant was given an initial practice run through the scenarios for familiarization.

Posttest Questionnaire

A posttest questionnaire was administered which subjectively rated how much the removable wrist splint and sugar-tong splint inhibited steering on a 1 to 5 Likert-type scale (1 = not at all, 3 = somewhat, 5 = very much) and how much the spinner knob helped steering (1 = not at all, 3 = somewhat, 5 = very helpful).

Statistical Analysis

The data were analyzed with IBM SPSS Statistics and Microsoft Excel. Prior to all analyses, data were investigated for outliers and to ensure that the assumptions of parametric statistical analyses were met using Mauchly’s test for sphericity, with nonparametric data requiring Huynh-Feldt correction. For each scenario and condition, the estimated marginal means, the standard error, and the 95% confidence interval were calculated. Hypotheses 1 and 2 were analyzed using repeated-measures analysis of variance (rANOVA) with appropriate paired comparison follow-up tests (paired samples *t* tests). Gender interaction was analyzed using both within and between subject comparisons.

Results

For the Reaction Timer Steering test, mean reaction time for the immobilization conditions ranged from 0.60 to 0.64 seconds (Figure 2). Statistical significance was not reached when comparing test conditions ($P = .051$). As a group, male participants had a mean reaction time of 0.63 seconds (95% confidence interval [CI], 0.59-0.67) and female participants had a mean reaction time of 0.60 seconds (95% CI, 0.55-0.64). There was not a statistically significant difference between males and females ($P = .279$) or the different test conditions based on gender ($P = .611$).

Table 2. Reaction Timer Steering—Scenario Description.

Task name	Reaction Timer Steering
Task description	<p>Goal: To turn the steering wheel left or right as quickly as possible.</p> <p>Description: An arrow was displayed to the left or right and records the time required for the participant to respond by turning the steering wheel in the direction of the arrow. In between arrows, the steering wheel was required to be returned to the 12-o'clock position prior to the next arrow and the word "ready" appeared on the screen. The scenario included an initial practice set of 4, followed by 20 trials.</p>
Target

Table 3. Steering Chase—Scenario Description.

Task name	Steering Chase
Task description	<p>Goal: Turn the wheel to keep the line in the moving target zone.</p> <p>Description: A steering wheel was displayed with a target zone highlighted. The line represented the position of the wheel. The participant turned the wheel to keep the yellow line in the moving target zone. The target zone moved about the wheel covering 2 full turns with multiple changes in direction. The outputs were steering accuracy represented by the number of errors or number of times the steering wheel was outside the target zone. Images are copyright of DriveSafety.</p>
Target Level 2	<p>Target zone size = 45°</p>
Target Level 3	<p>Target zone size = 30°</p> <p>Speed = 35% faster than level 2</p>

Figure 2. Mean steering reaction time.

Note. Error bars indicate standard error.

Table 4. Steering Chase—Level 2, Mean Number of Errors.

	Mean	SE	Lower 95% confidence limit	Upper 95% confidence limit
No immobilization (control)	0.3	0.2	0.0	0.6
Wrist splint	0.9	0.3	0.3	1.4
Spinner knob, wrist splint	1.2	0.3	0.6	1.8
Sugar-tong	1.8	0.6	0.6	3.0
Spinner knob, sugar-tong	0.5	0.2	0.1	0.8

Figure 3. Steering Chase—Level 2, mean number of errors.

Note. Error bars are standard errors.

*Pairwise statistical significant difference between the condition and the no immobilization (control).

Steering Chase was divided into 2 tests based on difficulty, level 2 and level 3. For Steering Chase—Level 2, the mean number of errors made in each condition is summarized in Table 4 and Figure 3. Mean number of errors (standard error) for Steering Chase—Level 2 were as follows:

control—no immobilization 0.3 (± 0.2), wrist splint 0.9 (± 0.3), wrist splint and contralateral spinner knob 1.2 (± 0.3), sugar-tong splint 1.8 (± 0.6), and sugar-tong splint and contralateral spinner knob 0.5 (± 0.2)/13.0 (± 1.0). Mean number of errors (standard error) for Steering Chase—Level

Table 5. Steering Chase—Level 3, Mean Number of Errors.

	Mean	SE	Lower 95% confidence limit	Upper 95% confidence limit
No immobilization (control)	7.6	0.68	6.2	9.0
Wrist splint	10.9	1.20	8.4	13.4
Spinner knob, wrist splint	12.2	1.42	9.2	15.2
Sugar-tong	12.4	1.82	8.5	16.2
Spinner knob, sugar-tong	13.0	1.05	10.8	15.2

Figure 4. Steering Chase—Level 3, mean number of errors.

Note. Error bars are standard error.

*Pairwise statistical significant difference between the condition and the no immobilization (control).

3 were as follows: control—no immobilization $7.6(\pm 0.7)$, wrist splint $10.9(\pm 1.2)$, wrist splint and contralateral spinner knob $12.2(\pm 1.4)$, sugar-tong splint $12.4(\pm 1.8)$, and sugar-tong splint and contralateral spinner knob $13.0(\pm 1.0)$. A significant difference was found between the study conditions ($P = .023$, by rANOVA). Pairwise comparisons revealed significant differences in the wrist splint, the wrist splint using the spinner knob and the sugar-tong splint conditions when compared to the no-immobilization (control) condition. For Steering Chase—Level 3, the mean number of errors made in each condition is summarized in Table 5 and Figure 4. A significant difference was found between the study conditions ($P = .002$, by rANOVA). Pairwise comparisons revealed significant differences in the wrist splint, the wrist splint using the spinner knob, the sugar-tong, and the sugar-tong using the spinner knob conditions when compared with the no-immobilization (control) condition. Gender had no significant effect during either Steering Chase difficulty level.

On the posttest questionnaire, participants gave their opinion on how much each splint type inhibited steering (Figure 5). The mean impression for the wrist splint was that it “somewhat” inhibited steering (13 of 20 stated “3, somewhat inhibiting”); for the sugar-tong splint, it was between “somewhat” and “very much” inhibitory to steering (17 of

20 chose 4 or 5 with 5 being “very much inhibiting”). Participants also rated how helpful the spinner knob was in assisting steering with each splint type (Figure 6). For both splints, participants’ mean impression was that the spinner knob was between “somewhat” and “very helpful” (18 of 20 chose between “3, somewhat inhibiting” and “5, very inhibiting” for both types of splint). In the posttest questionnaire, the results were for qualitative purposes, so result means were correlated to the description of the Likert-type scale and statistical difference was not calculated between groups.

Observational data quantifying the use of the immobilized arm differed across the steering conditions (Table 6). All testing scenarios had a similar trend of results within each condition, so all data were grouped by condition for comparison. Of the 2 immobilized conditions, the sugar-tong splinted extremity was used the least during steering tasks. The spinner knob conditions further reduced the percent time the splinted extremity was used by roughly 50% for both types of splints.

Discussion

Overall, steering accuracy was significantly compromised by upper extremity immobilization as was evident in the Steering Chase scenarios. For both the level 2 and level 3

Figure 5. Posttest questionnaire: How inhibitory was each splint type?

Note. Error bars indicate standard error. The scale was from 1 to 5 (1 = not at all, 3 = somewhat, 5 = very much).

Figure 6. Posttest questionnaire: How helpful was the spinner knob?

Note. Error bars indicate standard error. The scale was from 1 to 5 (1 = not at all, 3 = somewhat, 5 = very much).

Table 6. Subjective Observational Data Quantifying the Use of the Immobilized Upper Extremity (or in the Control Condition Two-Handed Steering).

	Mean use during testing (SE)
No immobilization (control)	95 (1.5) %
Wrist splint	67 (4.3) %
Spinner knob, wrist splint	37 (4.4) %
Sugar-tong splint	38 (4.2) %
Spinner knob, sugar-tong splint	16 (3.0) %

tests, the results were similar; showing the wrist splint and the sugar-tong splint conditions had significantly more steering errors when compared with the control group. These results are also consistent with the participants' perceptions in the posttest questionnaire. For clinicians, knowing upper extremity immobilization in a wrist splint or sugar-tong splint decreases steering accuracy may be valuable when counseling patients on returning to driving.

Upper extremity immobilization did not significantly affect reaction time. This result is not surprising since the test appropriately allowed participants to use their left, non-immobilized arm to turn the wheel. This finding differs from driving studies examining the lower extremities where reaction time can be significantly affected due to a single extremity actuating the brake pedal.^{6-8,13,14,18,19} However, the steering accuracy is dependent on reaction time; ie, the greater the reaction time, the more likely a steering error would be made because of delayed response. Because there was no difference found in the reaction time between any of the groups, it is surmised that the degradation of accuracy while splinted was not influenced by reaction time but instead related to the immobilization resulting in a loss of the ability to execute a specific motion required to maintain the steering wheel within the target zone.

Healthy participants were told to imagine they had a wrist injury. Their behavior was then observed and quantified. Not surprising, with no immobilization most participants utilized

2-handed steering most of the time. Once immobilized, there was a trend to decrease the use of the immobilized arm, relying more on the left arm for steering. Participants utilized their immobilized arm more for steering when in the wrist splint than when in the sugar-tong splint. With the spinner knob, the use of the immobilized arm further decreased. In general, the greater the degree of immobilization, the more participants relied on 1-handed steering.

The steering wheel spinner knob did not consistently improve steering accuracy. By adding the spinner knob, the only significant difference was found in improving the number of errors to the sugar-tong splint condition in the Steering Chase–Level 2 scenario. Despite this finding, the posttest questionnaire revealed the majority of participants found the spinner knob “helpful” with steering. The spinner knob, currently used in conjunction with hand controls for people who cannot use their lower extremities, provides persons with the ability to drive 1-handed. However, its utility in immobilized patients is still not known. In this study, a Driving Rehabilitation Specialist did not provide participants with formal training on the use of the spinner knob. Perhaps with such additional instruction or practice, there would have been more consistent results. All participants had their dominant (right) arm immobilized and relied on their nondominant arm for steering with the spinner knob. Hand dominance may also have influenced the results.

It is important to note that steering wheel spinner knobs are often used as adaptive equipment to assist with driving. Although steering wheel spinner knobs are commercially available in the United States, they may not be available or legal to use in all locations around the globe.

To date, the literature offers little guidance for driving with an upper extremity immobilized. Several studies of upper limb immobilization on healthy volunteers evaluated their ability to drive a vehicle.^{2,4,9-11,17} Chong et al found that driving performance on a cone course degraded significantly for participants placed in a left, above elbow thumb spica splint and a left, below elbow splint.⁴ A weakness of the study was the use of law enforcement officers as participants and a performance-driving course, which do not represent the general population or normal driving conditions. Chong et al hypothesized that the vehicle door influenced the finding that left-sided immobilization led to degradation of performance. We were not able to test this finding because our participants were immobilized on the right, the side away from the driver’s door.

Gregory et al conducted a simulator study in which participants drove both with and without a wrist immobilization cast.⁹ The authors concluded a splint may have affected hazard avoidance and encouraged more cautious driving. However, their conclusions should be interpreted with caution. The study had a sample size of 8 participants. No difference was found in number of traffic

offenses or collisions, which may have been related to type II error or the confounder of participant decisions during driving. The present study eliminated the decision making needed for driving, instead focusing on the ability of an extremity to steer and react.

Strengths of the present study design include enrolling and evaluating healthy, equal number of gender participants as a subgroup; limiting the study to only right hand dominant participants to eliminate handedness as a potential confounder and testing the worse-case scenario; and randomly assigning the order of test conditions, which were counterbalanced to minimize any carryover effect of learning that could be achieved in a crossover trial. Furthermore, the study utilized a high-fidelity, realistic driving simulator. Specific steering tasks provided accurate, reproducible, and quantifiable data that allowed for comparison between conditions.

Study limitations include using noninjured participants, absence of a priori power analysis, and assumptions regarding the effects of steering on “safe driving.” Noninjured participants were used to isolate the effect each splint type has on steering by eliminating injury as a potential confounder. Consequently, how injury affects steering was not evaluated in this study. In addition, a formal power analysis could not be performed prior to starting the study, allowing for potential error in data interpretation. Our assumption that decreased steering accuracy or reaction time would have a negative impact on driving safety was not tested. If our assumption was correct, what degree steering accuracy constitutes “safe driving” still remains unknown. Finally, left-handed subjects were not recruited; future investigation may investigate the effect of handedness and immobilization.

Conclusion

Immobilization in a removable wrist splint or sugar-tong splint with or without use of a spinner knob for steering does not significantly affect steering reaction time; however, such immobilization does have a negative effect on steering accuracy. Accuracy was not dependent on the type of immobilization. The steering wheel spinner knob did not consistently improve accuracy. Further study is needed to determine its utility within a clinical population.

Authors’ Note

All data presented in this study can be accessed via confidential data sheets (Microsoft Excel). These data sheets are encrypted to protect patient privacy. However, if needed, these data sheets are easily accessible by members of our research team.

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Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Johnell O. Brooks has received royalties for simulation hardware DriveSafety and software sales through Clemson University (Clemson, South Carolina).

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