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Effects of Long (Above-Elbow) Upper Limb Immobilization on Simulated Driving Performance: An Experimental Pilot Study

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Abstract

Background: Driving a motor vehicle is essentially incompatible with a limb immobilization according to the Quebec road safety code. The incapacity to drive due to an upper limb immobilization has an important potential socio-economic effect for patients, yet there is no consensus on the impact of upper limb immobilization on driving safety.

Materials and Methods: Our study aimed to characterise the effects of long upper limb immobilization on simulated driving. A sample of 12 healthy participants tested the effect of three conditions (without immobilization and immobilization of the left or right upper limb) on three independent tasks on a driving simulator: 1) maximal range of movement (ROM); 2) angular deviation and precision; and 3) impact of the immobilization during on-road simulated driving. Participants were also tested for grip strength and completed a questionnaire on perceived difficulty, insecurity, physical discomfort and fatigue.

Results: The data from absence of immobilization was compared to left or right arm immobilization. Maximum ROM to the right and left were significantly diminished with respective immobilizations, as well as angular deviation (p=0.019; p=0.050) and precision (p=0.019; p=0.028). No significant differences were observed however for the tasks of on-road simulated. Hand-grip was significantly reduced with an immobilization and participant's perception of difficulty and insecurity increased with an immobilization on either arm.

Conclusion: Above-elbow upper limb immobilization significantly affected ROM in a driving simulator and increased perceived difficulty and insecurity. As such, both left and right arm immobilization may affect driving performance and safety.

Keywords: Orthopaedic immobilization; Upper limb immobilization; Motor vehicle driving; Driving simulator; Road safety

Introduction

A fracture is not only a traumatic event for a person, but can also be very incapacitating due to the immobilization of the limb during treatment. While immobilized, patients often must continue their occupations, personal interests, community and daily activities, which most frequently requires the necessity of driving their motor vehicle. The present literature is very sparse and divergent regarding driving with a limb immobilization, especially with respect to the upper limbs. The evidence-based guidelines when it comes to advising immobilized patients regarding their ability to drive are sparse. In the absence of clear recommendations, physicians often advise their patients to abstain from driving with their immobilization [1], which is known to compromise their emotional and physical well-being, along with quality of life and evaluation of self-worth [2]. As such, patients often admit to driving with their immobilization [3-5] regardless the lack of information available pertaining to the safety of such practices. In a survey of 168 patients with an upper limb cast, a total of 50% responded that they drove at least once with their immobilization, and 22% mentioned that they drove daily while wearing a cast [4].

Unfortunately, the sparse available objective evidence regarding driving safety while wearing an upper limb immobilization (short or long) is contradictory. Stevenson et al. [6] suggest that it is safe to drive in below-elbow neutral casts, Bennett's type casts on either arm and in right above-elbow cast with adaptive measures such as moving the seat closer to the wheel (for above-elbow cast) or releasing the handbrake with the index finger instead of the thumb (for Bennett's casts). However, in the same study, the authors advise against driving with an above-elbow cast on the left arm because it proved to be significantly unsafe (it is uncertain though whether it was related to the vehicle's cockpit or the possible effect of dominant hand). Along the same recommendation, Chong et al. [7] suggest that driving performance is significantly diminished when wearing an above-elbow immobilization on the left arm. This aligns with the findings of Kalamaras et al. [4] who concluded altogether that patients should not drive in a long arm upper limb cast. Moreover, in a study geared towards driving with below-elbow upper limb immobilization, the authors concluded such

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immobilization appears to have little effect on the ability to drive a car unchallenged, yet adversely affects responses to routine hazards more prevalent and severe on the right arm [8,9] with similar results obtained by two other groups [9,10]. As such, clear guidelines are difficult to determine.

In the light of these different results, this study aims to evaluate the effects of driving with a long upper limb immobilization in regard to driving performance and safety. In this pilot study, as in the majority of studies on driving safety, a driving simulator was used for its cost-effectiveness, safety and ethical amicability [11-13].

Materials and Methods

Population and recruitment

Upon the approval of the Ethics Committee of the Research Center on Aging at the Health and Social Services Centre-Institut Universitaire de Gériatrie de Sherbrooke (CSSS-IUGS) for this pilot experimental study, volunteers aged between 18 and 60 years in possession of a valid driver's license with two years or more of driving experience capable of driving an automatic transmission car were recruited using flyers, personal contacts and the snowball method. Exclusion criteria included: pathologies known to affect driving abilities; abusive use of alcohol, drugs or psychotropic medication; motion sickness; and invalidating visual or skeletal impairments. The participants were representative of an average population, and each acted as his own control.

Driving simulator

In order to recreate the real space available in the cockpit of a car, a real non-motorized carcass was used (2000 Chevrolet Malibu). This automatic transmission car was then placed in a garage at the research centre with the front wheels over plates allowing for tire mobility (Figure 1); the instrumentation of the car permitted the measurement of turning angles through tire rotation. A spring was attached to the cable connected to the pedal of the accelerator to allow resistance to palliate the absence of the engine. The master cylinder of the braking system was missing therefore, it was necessary to connect the hydraulic system in a loop to recreate the effect of the brake. For simulated vehicle control, the steering column was instrumented with a linear potentiometer. The different driving scenarios using STISIM Drive Software were elaborated in order to be sufficiently challenging according to the aim of the study, and were projected on a 3 × 6 feet screen in front of the vehicle. In order to prevent or reduce the participant's discomfort while conducting the tests on the simulator, Stern's protocol (2006) was applied.

Procedure

Following informed consent and collection of sociodemographic data, each participant was permitted a practice session on the driving simulator before the actual simulated protocol began. For each participant, three independent conditions were investigated: driving without immobilization, driving with a right above-elbow arm immobilization and driving with a left above-elbow arm immobilization. The order of occurrence of each condition was randomized to minimize confounding bias. The upper-arm immobilization was installed and removed by a qualified professional. Total time to complete data collection was 60 minutes, including the time to complete the questionnaires, the three driving tests sequence and the cast installation and removal.

A B

Figure 1: Simulator set-up A) An image of the simulator's cockpit, created from a non-motorized carcass of a Chevrolet Malibu 2000. B) Image representing the simulator, with the front wheels over plates allowing for tire mobility, placed in front of a screen projecting simulated images for the tasks.

Measurements of driving performance

Driving performance was assessed on the simulator using a combination of controlled tasks (Task-1: maximum range of motion (ROM) in turning the steering wheel; Task-2: ability to react to sudden distraction) and simulated driving scenario (Task-3). For Taks-1, participants were instructed to keep both hands on the car's steering wheel at all times at the 10:2 position in accordance to driving safety examination guidelines. Both left and right maximum ROM were measured; the subjects were asked to turn the steering wheel to the maximum amplitude possible to the right and to the left without time constraint and with as many tries as they wished. One measurement for each was registered. Task-2 was designed to be representative of emergency maneuvers in terms of visual-perceptual abilities and speed of information processing related to time constraint. During this task, the actual steering wheel orientation was represented by a green needle and the desired orientation, by a red needle (Figure 2). Every two seconds, the red needle was automatically moved to one of the twenty-three predetermined angular positions. Participants were instructed to follow the red needle as quickly and precisely as possible. The ability to react to sudden distraction was measured using the angular deviation concept, defined as the difference between the stabilized angular position of the steering wheel and the targeted angular position, as well as the angular precision concept, defined as the difference between the over or under achieved angle during the pursuit of the target and the actual target position. For example, if the targeted angle is 60° and the subject reaches 68° but stabilizes his efforts at 63° then, angular deviation are 3° while angular precision is 8°.

The on-road driving test (Task-3) assessed trajectory control which refers to the operational aspect of driving representative of driver's behavior in actual driving situations. For this task, participants were asked to follow a standardized path as rigorously as possible without constraint of time or speed, but keeping both hands on the wheel (Figure 2). Collected variables include time to completion, average speed and off-road driving parameters (number of off-road driving events, distance travelled on either side of the road during such events and the duration of the events).

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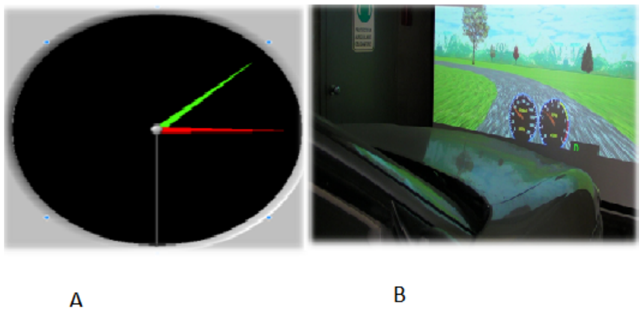

Figure 2: Simulator driving test interface A) Image showing the angular precision and deviation test in which participants had to turn the steering wheel to follow the red needle. B) An image of the on-road driving test interface that required participants to keep both hands on the wheel whilst following a standardized path as rigorously as possible without constraint of time or speed.

In addition to the driving tasks, several descriptive variables were measured for each of the independent conditions tested (right above-elbow arm immobilization, left above-elbow immobilization and no immobilization). Handgrip strength was measured with a JAMAR® dynamometer. Participants were asked to grip as tightly as possible three consecutive times, and the average strength was recorded. Participant perception in regards to difficulty, safety, physical discomfort and fatigue was also measured with visual analog scales (VAS) from 0 (none) to 10 (extreme) after each tests sequence on the simulator (i.e. for each independent condition).

Statistical analysis

For the sociodemographic questionnaire, for the continuous variables, mean average and standard deviation were calculated while for the categorical data, percentage was presented. In the data generated for the angular precision and deviation, the first and last angular positions were excluded from the analysis as they were prevaricating the results. For the variables associated with the driving simulator, a non-parametric Friedman test was done followed by a Wilcoxon signed ranked test with alpha equal to 0.05.

Results

Twelve (12) volunteered participants were recruited with mean age of 31.58 and an equal distribution of male and female participants (Table 1). For the comparisons, right and left arm immobilization were each compared to the absence of immobilization. In terms of the maximum ROM to the right there is significant difference $p<0.001$ when comparing right-hand immobilization and lack thereof (Table 2, $p<0.001$). A significant difference was found for the maximum ROM to the left both with right-arm ($p=0.038$) and left-arm ($p<0.001$) immobilization when compared to the absence of immobilization (Table 2). For both right and left arm immobilization the hand-grip was also significantly decreased (Table 2, $p<0.001$). Participants perceived that it was significantly more difficult and unsafe to drive with both right and left arm immobilization (Table 2, $p=0.003$).

Characteristics		Mean ± SD	Number (n)	Percentage (%)
Age (years)		31.58 ± 11.45	-	-
Weight (lbs)		162.17 ± 36.86	-	-
Height (m)		1.69 ± 0.10	-	-
Driving experience (years)		13.5 ± 12.01	-	-
Driven kilometers annually (× 1000)		16.67 ± 9.37	-	-
Number of collisions (road accidents)		1.08 ± 1.17	-	-
Number of driving infractions (excluding parking)		1.25 ± 1.60	-	-
Perceived tiredness before study		3.29 ± 1.25	-	-
Hand length (cm)		18.75 ± 1.23	-	-
Forearm length (cm)		25.63 ± 3.05	-	-
Arm length (cm)		29.96 ± 3.41	-	-
Gender	Men	-	6	50
	Women	-	6	50
Dominant hand	Right	-	11	92
	Left	-	1	8
Ability to drive automatic transmission vehicle	Yes	-	9	75
	No	-	3	25

Upper limb immobilization experience	Below elbow	-	2	17
	Above elbow	-	1	8
	None	-	9	75

Table 1: Sociodemographic and anthropometric characteristics and driving experience (n=12).

In simulated driving conditions, normalized angular deviation have shown a significant difference with right (p=0.019) immobilization as compared to the control (without immobilization, but not with left (p=0.050) immobilization, Table 2). However, for the angular precision, no significant differences were noted. For all the parameters of simulated on-road driving (total time to complete the course, average speed and all details regarding road deviation), no significant difference was observed (Table 2).

Clinical outcomes		Conditions			p-value		
		Without Immobilisation (NoC) (Mean ± SD)	Right arm Immobilisation (RC) (Mean ± SD)	Left arm Immobilisation (LC) (Mean ± SD)	Global Difference*	Difference NoC–RC **	Difference NoC-LC**
Clinical parameters							
ROM to the right (o)		153.89 ± 9.57	97.62 ± 9.57	135.36 ± 9.57	p<0.001	p<0.001	p=0.097
ROM to the left (o)		-151.93 ± 9.35	-136.35 ± 9.35	-93.01 ± 9.35	p<0.001	p=0.038	p<0.001
Norm. Angular deviation (%)		5.6 ± 3	10.7 ± 7.9	9.5 ± 4.8	p=0.017	p=0.019	p=0.05
Norm. Angular precision (%)		5.6 ± 3	11.8 ± 5.5	11.2 ± 3.1	p=0.125	--	--
Hand grip	Right	37.39 ± 10.78	24.37 ± 12.41	--	--	p<0.001	--
	Left	36.55 ± 10.60	--	24.57 ± 12.89	--	--	p<0.001
Autoperception questionnaire	Difficulty	2.67 ± 2.19	5.38 ± 2.14	5.71 ± 1.60	--	p=0.003	p=0.003
	Security	1.0 ± 1.28	3.83 ± 2.33	4.50 ± 2.75	--	p=0.003	p=0.003
	Discomfort	0.17 ± 0.58	1.83 ± 2.41	1.42 ± 2.07	--	p=0.078	p=0.058
	Tiredness	1.08 ± 1.51	1.75 ± 1.49	1.83 ± 1.64	--	p=0.066	p=0.066
Simulated driving							
Total time for completion of the simulated path (s)		73.69 ± 3.33	78.51 ± 3.33	76.79 ± 3.33	p=0.177	p=0.134	p=0.411
Average speed during the path (m/s)		35.14 ± 1.30	33.29 ± 1.30	34.09 ± 1.30	p=0.239	p=0.181	p=0.555
Total time of off-road driving (s)		40.71 ± 3.46	38.98 ± 3.46	40.94 ± 3.46	p=0.634	p=0.690	p=0.994
Total distance for off-road driving		43.81 ± 3.70	40.62 ± 3.70	42.94 ± 3.70	p=0.331	p=0.284	p=0.904
Total amount of off-road driving		14.33 ± 0.94	14.83 ± 0.94	14.33 ± 0.94	p=0.839	p=0.849	p=1.000
Total average time for off-road driving		2.21 ± 0.22	2.18 ± 0.22	2.25 ± 0.22	p=0.947	p=0.984	p=0.982
Total average distance for off-road driving		23.32 ± 1.94	20.66 ± 1.94	22.28 ± 1.94	p=0.286	p=0.227	p=0.783
Amount of off-road driving to the left		2.33 ± 0.91	3.58 ± 0.91	2.42 ± 0.91	p=0.208	p=0.216	p=0.993
Average time of off-road driving to the left		0.51 ± 0.15	0.40 ± 0.15	0.59 ± 0.15	p=0.385	p=0.688	p=0.786
Average distance of off-road driving to the left		5.34 ± 1.54	4.14 ± 1.54	6.37 ± 1.54	p=0.335	p=0.669	p=0.740
Amount of off-road driving to the right		12.00 ± 0.37	11.25 ± 0.37	11.92 ± 0.37	p=0.302	p=0.296	p=0.984

Average time of off-road driving to the right	2.40 ± 0.23	2.50 ± 0.23	2.40 ± 0.23	p=0.886	p=0.896	p=1.000
Average distance of off-road driving to the right	25.50 ± 2.15	24.08 ± 2.15	24.11 ± 2.15	p=0.655	p=0.670	p=0.680
* Friedman test, α set at 0.05 **Wilcoxon signed ranked, α set at 0.05						

Table 2: Simulated on-road driving.

Discussion

Driving performance is attributable to control maneuvers, trajectory control and reaction to obstacles, such as pedestrians and emergency reactions. The operational level of driving relates the information processing speed and visual perceptual abilities to perform the actions [14,15]. Control maneuvers, trajectory control and reaction to obstacles reflect the subject's physical abilities; time constraint linked to control maneuvers and reaction to obstacles can be challenging as reaction time may be affected by physical limitations such as an arm immobilization. The perception of the added challenge may be sufficient to alter one's decision to drive with the limitation. At first glance, patient perception may seem unimportant, yet one's perception of their ability to drive will determine their final decision to that effect [7]. In this pilot study, like in the Chong's study, they could have an increase in participants' perceived difficulty and insecurity with an above-elbow arm immobilization in comparison to the absence of immobilization. It is important to note that, considering the impacts on their daily activities, 50% of the patients with an upper limb immobilization have been shown to choose to drive despite their perception of increased difficulty and insecurity [4]. This underlines the importance of providing evidence-based guidelines for driving instructions with an immobilization.

As such, in this pilot study, we principally concentrated our evaluation on control maneuvers including maximum ROM, angular deviation and precision. Upon analysis of the maximum ROM, we found significant differences with an above-elbow immobilization. Left immobilization significantly affected full ROM to the left, yet ROM to the left and to the right were both significantly decreased with a right arm immobilization. This implies that large amplitude turns in driving situations are affected and may alter the driving security more so with the right arm in an above-elbow immobilization. This finding coincides with those of Gregory et al. [8]. However, Gregory's study was conducted in the United Kingdom, where the layout of the car's cockpit is different, in that the driver side is on the right. As the armrest to the right may be conjectured to have been a nuisance with right arm immobilization for the vehicle in Gregory's study, the car door may have been as well in our study. In addition to the car's door on the side of the immobilization representing a limitation to driving performances, in this study, the armrest proved to be as well. In their study, Hasan et al. [16] results suggested that sling immobilization of the dominant driving arm decreases driving performance and safety in terms of number of collisions in a simulated driving circuit. However, in our study, only one subject presented the left arm as dominant, therefore, it is unlikely to be able to discriminate the impacts of hand dominancy in relation to driving performance amongst the subjects. Finally, left arm immobilization is limiting to the maximum ROM to the left, in conjunction with observations made by Chong et al. [7] whose study was conducted in the United States of America.

In terms of trajectory control (the on-road simulation driving), the absence of significant outcomes concurs with Hasan's findings [16]. There may be two possible explanations for our observations: 1) participants used their free thumb and the hollow of the palmar joint for better grip on the steering wheel and therefore better control; and/or 2) the trajectory scenario may have been less discriminatory than anticipated. The use of the palmar crease was observed as well in Kalamaras' study [4], which confirm that the participants resort to compensating adjustments when incapacitated by the immobilization. Even though the immobilization may be restraining, adaptive measures were developed by the participants to compensate the limitations and thus enabling them to drive unencumbered along a trajectory without hazardous events. This is in agreement with Gregory and al. [8], where they found driving deteriorates in response to hazardous events.

Normalized angular deviation, which was designed to portray the reaction to emergency maneuvers in terms of visual-perceptual abilities and speed of information processing related to time constraint, was significantly affected by an immobilization on the right arm, but not on the left. On the other hand, Mansour et al. [10] concluded that driving with a short arm cast did not significantly decrease steering ability in a driving simulator. This divergence could be explained by the type and length of the immobilization (long vs short and rather elbow joint was immobilized or not); the extent of functional impairment by immobilization is based on the type of immobilization device, side of immobilization with regards to handedness, the length of the cast 10. Chong et al. [8] found that a splint on the left arm (especially above-elbow thumb Spica splint) was associated with significant driving performance degradation but hand dominance could not be singled out as a factor due to small sample size. It was suggested in the same study that the worsened performance on the left immobilized arm was potentially due to visual and spatial constraints associated with a left-sided drive seat. In our study, length of the cast (long) as well as hand dominance and the arm rest of the car (cockpit configuration) could explain the difference observed between the two studies since most subjects, except for one, reported being right handed and the right arm immobilization proved to be significantly more encumbering. In a post hoc analysis, Gregory et al. [8] revealed that right hand dominance of the participants in their study could explain more pronounced deterioration with right arm casts; their study however was conducted in the UK where the cockpit configuration is different. Chong et al. [8] suggests that an alternate explanation for more pronounced deterioration of driving performance is having the immobilized arm on the same side as the driver's seat which is not what is observed in our study and therefore the divergence could be attributable to the arm rest of the car used for our study. Hasan et al. [16] suggest altogether that sling immobilization does impede the driver's ability to effectively perform evasive maneuvers because the use of a single upper extremity is not sufficient to properly react to road hazard. In accordance, though not statistically significant, the immobilization on the left arm also indicates a decrease in driving performance in terms of emergency maneuvers as well as the right arm (which proved to be statistically significant). This also converges with Kalamaras et al. (2006) advising against driving in a long upper arm cast as it was deemed unsafe especially when it comes to executing turns and reverse parking. However, having normalized angular precision not generating any significant result may be explained by the way the test was initially designed and could be attributed to three possible reasons: the angle values were not equitably distributed around 0°; the number of left turns was not equal to the number of right turns (eight *vs.* fourteen in addition to the initial angle); and left turn angles were generally wider than the right ones. Therefore, this generated results that were, in general, more tedious to analyse and as such unsuccessful in showing discriminant observations. Furthermore, we show a significant decrease in handgrip with an immobilization on either arm, which implies decreased steering grip aptitude, thus diminished control for maneuvers necessary to react to obstacles and emergency situations. Consequently, on-road driving without hazardous challenges is not incapacitating with an arm immobilization on either side, it is rather the responses to hazardous events that proves to be significantly more challenging and incapacitating, especially on a right arm immobilization. The use of a simulator in this type of study is justified on an ethical point of view (i.e., security). However, the validity of the results is directly related to the representativeness of the set-up as and the tasks performed. As described earlier, the set-up was built out of a real car to ensure representativeness of the physical restrictions involved in driving (physical obstacles such as the door, steering wheel force feedback). Driving performance was first evaluated using controlled tasks to isolate the desired aspect of driving (i.e., ROM and ability to react to sudden distraction), limiting confounding variables to act upon the results. On-road simulated task was performed using STISIM drive software, recognized as a reference for this type of study. However, the flat screen used to project the trajectory might have limited the realism of the situation. Despite these efforts to maximize validity, the actual impact of the identified limitations in true on-road situations is difficult to evaluate as it depends upon the type of vehicle used, the speed as well as the actual trajectory pursued.

Even though there are some limitations to this study, the findings contribute greatly to present literature as the results confirm the outcomes of some previous studies' observations, which adds weight to their value. It is also one of a few studies which concentrate on the characterization of above-elbow arm immobilization especially including many functional aspects of driving and therefore constitutes valuable basis for future findings. The professional diversity and multidisciplinary of the research team proved to be very valuable through the expertise injected in the project in terms of technical, conceptual and insightful contributions. However, the small sample size of this study brings certain limitations to the conclusions that may be extracted from the results such as the inability to determine whether laterality is a determining factor in this case. It would require a bigger sample and more testing to determine clinical significance, both left and right arm immobilization affect driving performance and safety. Therefore, it is advised to forego a more in depth investigation with more participants in order to validate the results as it may be valuable to also use a curved 180° (or even 360°) screen installation for the simulation.

Conclusion

We found that above-elbow right arm immobilization was significantly affecting, right and left maximum ROM of the steering wheel while left above elbow immobilization was only significantly affecting left maximum ROM. A significantly decreased handgrip, indicative of decreased grip aptitude, on both right and left above elbow immobilization and a significant effect on normalized angular deviation in right above elbow immobilization suggests the possibility of diminished control for maneuvers necessary to react to obstacles and emergency situations. Importantly, we also found that there is an increase in participants' perceived difficulty and insecurity while driving with an above elbow immobilization in a simulated condition. Therefore, above-elbow upper limb immobilization might have a significant effect on driving performance and more so for right above-elbow arm immobilization.

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