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Development of instrumentation and protocol to measure the dynamic environment of a modified van

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Abstract—The dynamic environment of a van modified to accommodate a person driving from a wheelchair was measured to determine the effects of position within the van and the type of seat used. The project measured accelerations as a subject sat in three positions within the van and upon two different seats. Three separate van maneuvers at different speeds were used to change the dynamic environment. Van accelerations at the different positions varied significantly. A wheelchair transmitted more accelerations to the subject than the original equipment manufacturers (OEM) seat, making it harder to maintain a stable posture. These results should prove useful to others studying the functional abilities of wheelchair users within a vehicle environment.

Key words: *disability, driving, seating, stability.*

INTRODUCTION

Certain wheelchair users are unable to independently transfer into a car from a wheelchair, and therefore, must enter a van while seated in a wheelchair. The van must be modified to accommodate the increased sitting height of a person in a wheelchair. These modifications change the vehicle dynamics by changing the inertial properties of the vehicle. The changes in vehicle dynamics, together with the differences in seating systems, produce a unique dynamic environment.

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In order to determine the effects of the dynamic environment on the stability and functional ability of a driver with a disability, the forces and accelerations within the driving environment must be understood. The dynamic environment experienced by the nondisabled driver has been studied extensively. However, little research has been performed that defines the environment experienced by the disabled driver. The two environments are different because of the differing abilities of the drivers and, in some cases, the differing responses of the vehicles and seating systems.

Vans are modified to accommodate a person driving from a wheelchair to allow adequate head room and correct line of vision from the vehicle. Because of the height of the wheelchair seat and cushion, a wheelchair user sits an average of 10.16–12.7 cm (4–5 in) higher than a person in an ordinary chair or vehicle seat. This increased seat height necessitates more head clearance for an individual to enter the vehicle while in a wheelchair. The roof of the van can be raised to accommodate this need. To provide an appropriate line of vision through the vehicle windshield and adequate clearance under the steering column, the floor of the van must also be lowered. These modifications and the installation of a 75 to 150 kg wheelchair lift change most of the inertial properties of the vehicle such as mass, mass distribution, and location of center of gravity (1,2). These qualities, together with tire cornering stiffness, are the major influences on the steady state handling characteristics of any vehicle (1).

Human performance in any moving environment is a function of the dynamics of the environment and the nature of the task performed. Much of the research that has been performed on dynamic vehicular environments focuses on vehicles at their performance limits or during emergency maneuvers. Literature available on human reactions to vehicular environments deals almost entirely with nondisabled individuals or crash test dummies seated in the original manufacturer's seating systems. Very limited information is available regarding the dynamics of vehicles after they have been modified to accommodate a passenger or driver seated in a wheelchair.

Mercer and Billings (3) developed driving tests appropriate to demonstrate the performance of a scooter tie-down system. A 50th percentile male dummy was seated on a scooter and secured with a lap belt and shoulder harness. The scooter was secured in a 1990 Ford van which had been modified for transport of passengers in wheelchairs. The vehicle was instrumented to measure angular displacements and velocities, vehicle speed, and linear accelerations of the vehicle along its coordinate axes. Longitudinal and lateral displacement of the scooter base and seat were measured, and the load in each of the rear harness tie-down belts was measured with force links. Additionally, two video systems were used to monitor the scooter/dummy system.

The tests performed were designed to measure the response of the scooter as a function of the longitudinal and lateral accelerations of the vehicle. The vehicle maneuvers included those suggested by CAN3-D409-M84 Canadian standards for wheelchair tie-downs: straight-line accelerations (0–40 km/hr at full throttle), straight-line braking (maximum braking from 35–0 km/hr), and steady lateral accelerations (constant 30 m diameter curve at 26 km/hr) (4). The acceleration maneuver produced longitudinal acceleration which initially peaked at 0.33 g and approached a steady 0.17 g once the vehicle was in motion. Maximum braking produced decelerations of 0.77 g, and the constant curve driving sustained an average lateral acceleration of only 0.38 g (3).

Objectives

The goal of the current project was to design instrumentation and testing protocols that could be used to define the dynamic environment presented by a vehicle that had been modified to accommodate wheelchair users. This study concentrated on identifying the effects of important variables like seat type and seat position within the vehicle, and quantifying the magnitudes and variation of accelerations during repeated trials. The methodology was designed so that the information collected during this pilot study could then be used to design studies that focus on the effects of different wheelchairs, seating systems, and van modifications on the stability and function of a wheelchair user in a moving vehicle.

Instrumentation

The data quantified the dynamic environment in different locations in a vehicle: the driver area, front passenger area, and rear passenger area, and related the effects caused by different seating systems on the passenger. The data collected represented the dynamic input and output of the subject/seat system and consisted of the linear accelerations experienced by the van and the subject. These accelerations were measured with six piezobeam accelerometers[1] having a range of ± 5 g over a frequency of 0.25 to 10^5 Hz with an output range of ± 5 volts. The accelerometers were mounted on two tri-axial mounting cubes. To measure system input, one cube was mounted to a test jig located on the van floor to determine the dynamic response of a particular location. System output was measured with a cube attached to the sternum of the subject with medical tape.

The Megadac 2210C Data Acquisition System[2] was selected because of its capabilities. The system is portable and can latch and sample 128 channels of data, and a total of 20,000 samples can be taken per sec. Data are stored on a magnetic tape cartridge with a 60 Megabyte capacity and a throughput of 2200 samples/sec. The Megadac uses several different input/output Modules. The modules configured for use in this study are described below and diagrammed in **Figure 1.**

Two AD-884-SH analog-to-digital (A/D) modules were configured for input. Each latched and sampled eight channels and the gain of each channel was set individually. Additionally, signals into each channel are low-pass filtered with a four-pole active filter at a cut-off frequency of 80 Hz. After channel gain and filtering, signals were fed through a 16 bit ADC-2016 binary A/D converter with a calibrated range of $\pm 32{,}000$ counts corresponding to a voltage range of ± 10.5 volts. Channel gains on the input modules were selected to allow maximum discretization through the A/D converter while ensuring that the amplified signal did not exceed the range of the converter. The resulting precision of the accelerometer-data acquisition system was 0.002 g.

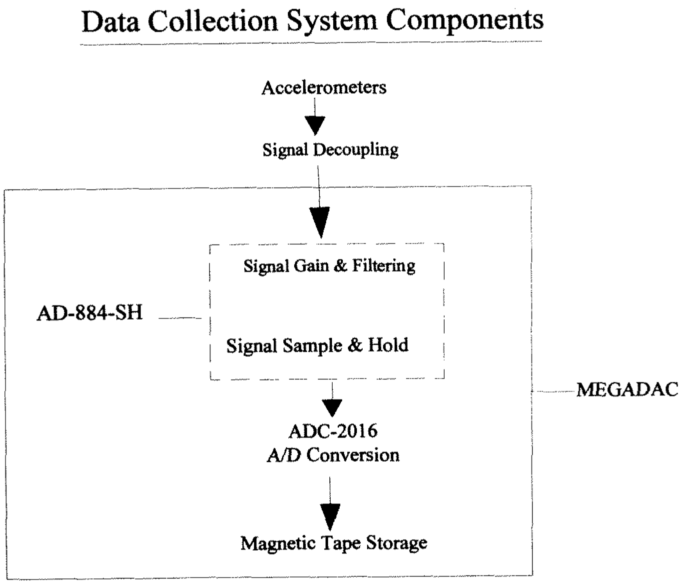

Figure 1.
Data collection system components.

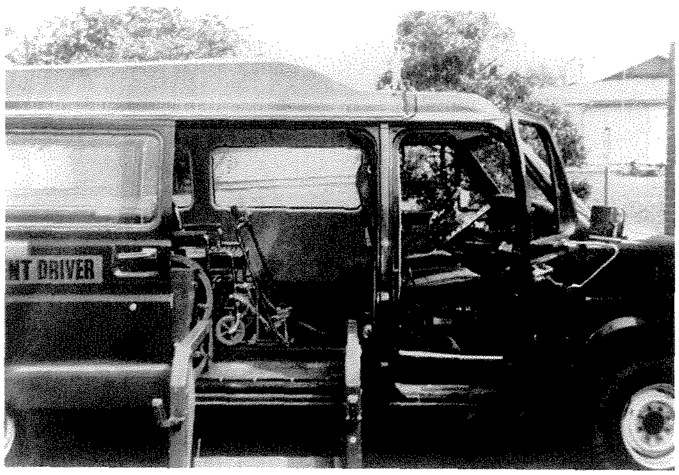

Figure 2.
Relationship between the different seating positions within the vehicle.

Since all of the equipment needed to be portable, a means for powering the system was provided. A 12-channel PCB Piezotronics 483B03[3] unit powered the transducers and decoupled their output. The unit was powered from 24 VDC supplied by two 12-volt Eveready Lantern Batteries (#732). The Megadac was powered by a 12-volt deep cycle battery.

METHODS

The dynamic input and output of the subject/seat system, characterized by the linear acceleration present at the vehicle floor and subject's sternum, were measured in different locations within the vehicle using different seats. Responses were measured with the subject seated in the manufacturer's driver seat, the front passenger seat, and a wheelchair secured in the driver's area and the rear passenger area. The relationship between these positions within the vehicle is shown in **Figure 2.**

The subject was a 24-year-old female, 157.48 cm (5 ft 2 in) in height and weighing 50 kg (110 lbs), with no known neuromuscular deficits or skeletal deformities. The driving evaluation vehicle was a modified 1990 Ford Econoline Van. The vehicle had a 15.24-cm (6-in) dropped floor, and a driver's floor pan allowing an adjustable depth of up to 20.32 cm (8 in). A standard wheelchair lift was installed on the right side of the vehicle.

The wheelchair was a standard adult manual chair with a 45.72 cm (18 in) seat width, 40.64 cm (16 in) seat depth, and a 43.18 cm (17 in) backrest height. The rear wheels had a 60.96 cm (24 in) diameter with pneumatic tires, and the front solid casters had a 17.78 cm (7 in) diameter. The seat height was 48.26 cm (19 in) from the ground, and a 7.62 cm (3 in) HR55 foam cushion was added to the seat. When the subject was a passenger, the wheelchair footrests were positioned so that her thighs were parallel to the ground. When driving, no footrests were used, as they interfered with the subject's ability to control the brake and throttle.

In the driver position, the manufacturer's driver seat and the wheelchair were used. In both cases, the chair was positioned to allow maximum control of the vehicle. The wheelchair was secured in the driver position with the brakes locked using a three-point belt tie-down system[4]. In the passenger position, the wheelchair was centered over the securement tracking. The brakes of the chair were locked and the casters were positioned parallel to the rear wheels of the wheelchair. The chair was secured using a four-point belt tie-down[5]. **Figure 3** shows the wheelchair securement system.

Subject response was measured by accelerometers mounted to a tri-axial cube. The cube was secured with medical tape so the accelerometers were located 2 to 3 cm inferior to the sterno-clavicular joint. The accelerometers measuring vehicle response were mounted on a tri-axial cube secured with double-sided adhesive tape to a heavy aluminum test jig. The jig had three pointed feet which were driven into the carpet on the vehicle

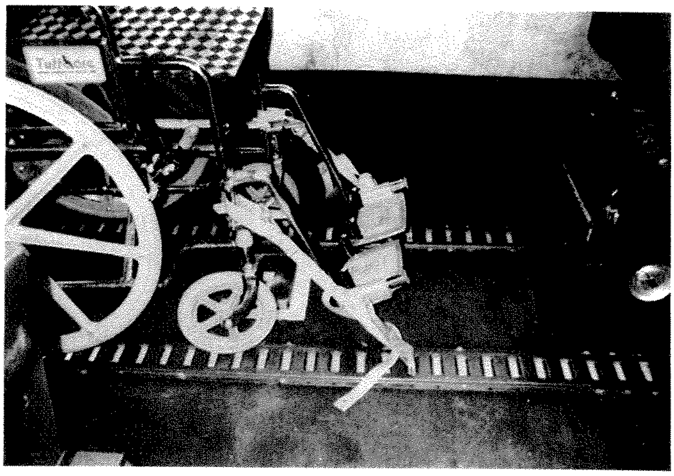

Figure 3.
Wheelchair secured with a four-point belt tie-down.

floor by the mass of the jig; thus, stabilizing it against the motions of the vehicle. The test jig was placed on the floor centered between the casters and approximately 25 cm behind the footplates.

Acceleration profiles of the vehicle and subject were collected while the vehicle performed several maneuvers outlined below. These maneuvers were selected because they represented common tasks in a normal driving experience. The maneuvers are similar to those of a previous study to test emergency driving conditions (3) with vehicle velocities chosen to simulate normal driving practices instead of emergency conditions.

1. Acceleration from rest. The vehicle was accelerated from standstill to speeds of 16.1, 32.2, and 48.3 km/hr (10, 20, and 30 mph) during an interval of 10 sec. Each test run was performed on a road with a slight grade. The exact times taken for the accelerations were recorded, and average accelerations were calculated.
2. Deceleration to rest. The vehicle was decelerated from speeds of 16.1, 32.2, and 48.3 km/h (10, 20, and 30 mph) to standstill during an interval of 4 sec. The same stretch of road used for acceleration testing was used for deceleration testing. The time taken for each deceleration was measured, and average decelerations were calculated.
3. Curve driving. The vehicle was driven around a curve at constant speeds of 16.1 and 32.2 km/hr. The vehicle path was defined on a driving range using orange traffic pylons. The path started with a straight section of 23 m (75 ft) to allow the vehicle to attain the appropriate velocity. The remainder of the path was driven at a constant velocity. Speeds higher than 32.2 km/hr were attainable, but were deemed non-repeatable and unsafe.

During the driving maneuvers, vehicle velocities were determined using the van's speedometer, which had been calibrated prior to testing. The subject drove when positioned in the driver area and the first author drove when the subject was in a non-driving position. Both were experienced in operating the test vehicle and had practiced each maneuver before data collection.

Four successful test runs were obtained for each maneuver and speed for each vehicle position and seat. Test maneuvers were deemed successful based on the following criteria: the vehicle could not leave the paved surface; excessive steering inputs were not allowed; and accelerations to a given speed had to be completed in not less than 9.5 and not more than 11.5 sec. Decelerations were completed in not less than 3.5 and not more than 5 sec. Curves were driven within ± 3.2 km/h (2 mph) of the target speed with a range of not more than 4.8 km/h (3 mph), and the vehicle maintained the designated path through the curve.

Data Reduction

During data collection, a logic on-off switch was used to record when a maneuver was being performed. This event signal channel was scanned to extract separate events from each data file.

Data from each event were analyzed using Matlab[6], a software package designed to handle large matrices of data. The output of each accelerometer was filtered using a tenth order Butterworth filter with a cut-off frequency of 10 Hz. The Butterworth filter was selected for its characteristically flat pass-band. A high order filter was used to compensate for the gradual roll-off characteristics of the filter. The cut-off frequency was selected based on the work of Linder who reported that vibration affects stability and muscle control in frequencies below 10 Hz (5).

A fast Fourier transform determined the accelerative frequencies present in the dynamic vehicle environment; a power spectral analysis showed the power delivered by the vehicle to the subject at each of these frequencies. Inspection of the power spectrum of the preliminary data showed that, for all vehicle maneuvers, 90 percent of the power of the signal resided in the frequency range from 0 to 1 Hz. Subsequent data were filtered at a cut-off frequency of 1 Hz.

Given the three orthogonal accelerations for the subject and the vehicle, the magnitude of the resultant acceleration vector was calculated as a function of time. This resultant vector was termed total acceleration. A root-mean-square (RMS) value was calculated to quantify the amount of acceleration present in each maneuver and represents the power imparted to the subject. The longitudinal RMS acceleration for the acceleration and deceleration maneuvers, and the lateral acceleration for the curve maneuver were considered the primary acceleration for the respective maneuver. RMS values were calculated for the total and primary accelerations of each maneuver. Calculations excluded the first and last 25 percent of the maneuver; thus, inertial effects at the boundary of the event were discarded.

A two factor analysis of variance was performed to determine the effects of vehicle speed and position within the vehicle on both the primary and total RMS acceleration values for the vehicle. The seating systems were compared by observing subject response while the subject was seated in the driver location in both the original manufacturer's (OEM) seat and the wheelchair. Statistical significance was defined at the $p<0.05$ level.

RESULTS

The differences in the dynamic environment at different locations within the vehicle were determined by examining the accelerations present on the vehicle floor for the driver, front passenger, and rear positions in the vehicle. **Figure 4** summarizes the accelerations present on the vehicle floor for the different vehicle locations.

A two factor analysis of variance showed statistically different RMS accelerations present at different locations on the vehicle floor for some of the maneuvers. During acceleration maneuvers, the effect of the position within the vehicle was statistically significant for primary accelerations ($p<0.005$) and total acceleration ($p<0.05$). During deceleration maneuvers, the effect of both speed and position on the primary acceleration were significant ($p<0.001$). These factors were interactive ($p<0.05$). For total acceleration, position and speed were both significant ($p<0.01$) and interactive ($p<0.01$). For the curve maneuvers, neither factor had a significant effect on either primary or total RMS acceleration.

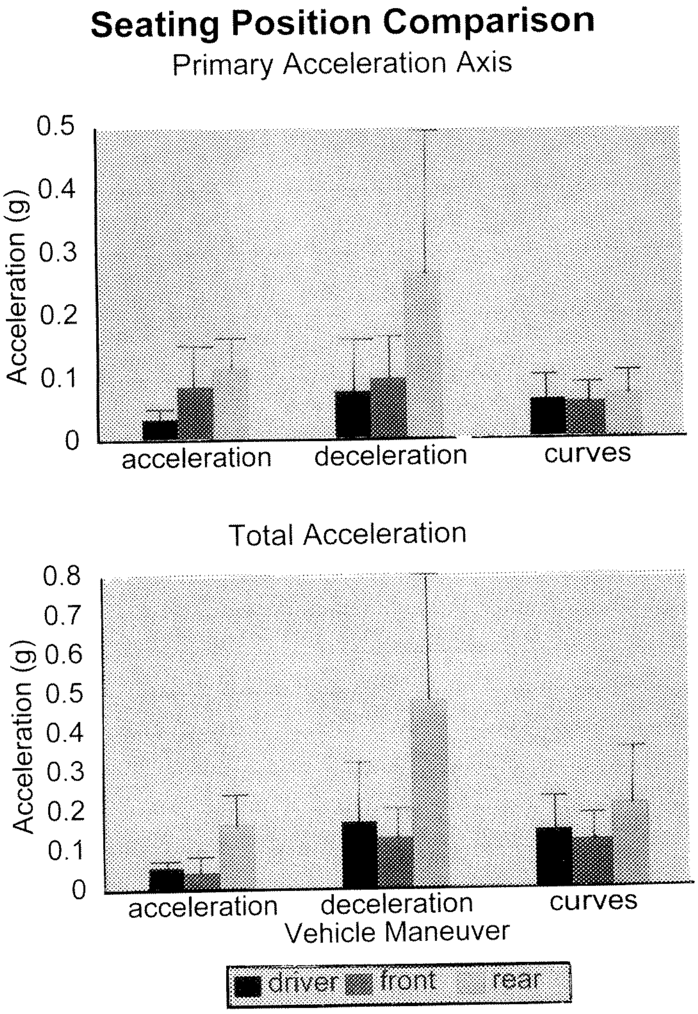

Figure 4.
The effects of seating position within the vehicle.

The effects of the seating system on subject response were compared by relating the subject response while seated in the OEM seat and the wheelchair secured in the driver area of the vehicle. A transmission ratio was defined as the ratio of the subject RMS acceleration to the vehicle RMS acceleration. **Figure 5** demonstrates the transmission ratio of each seat for each vehicle maneuver.

DISCUSSION

Comparison of the dynamics at different locations within the vehicle showed differences between the rear and the front of the vehicle. The front passenger and driver areas experienced comparable average RMS vehicle accelerations for both the primary and total

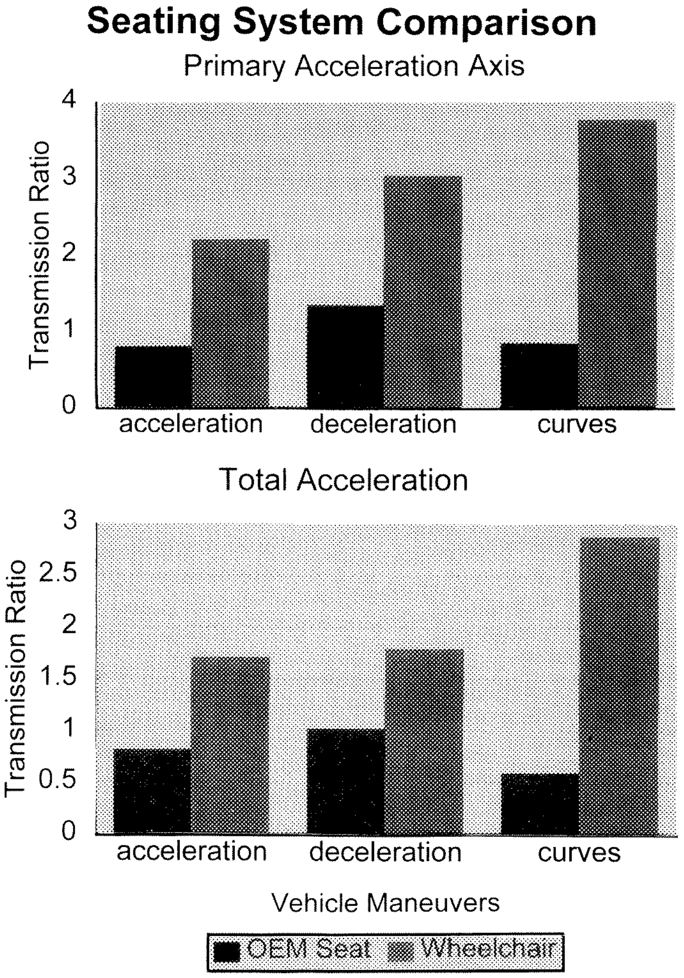

Figure 5.
The effects of seating system on subject acceleration.

accelerative axes. Both the primary and total rear RMS vehicle accelerations were much greater than those of the driver area, particularly for the acceleration and deceleration maneuvers.

The effect of position on vehicle dynamics was statistically significant for primary and total accelerations during acceleration and deceleration maneuvers, but not for curve maneuvers. During deceleration maneuvers, the effect of the position was dependent on the speed from which the vehicle decelerated. Pitching of the vehicle occurred during the 32.2 to 48.3 km/hr (20 to 30 mph) trials, but was not as noticeable during the 16.1 km/hr (10 mph) trials. As this pitching became more severe at higher speeds, its effects on the linear accelerations present at different locations within the vehicle changed.

The subject exhibited similar accelerations in the front passenger and driver locations, except during acceleration maneuvers. For these maneuvers, the driver showed a total acceleration an order of magnitude higher than the front passenger, even though the longitudinal accelerations were similar. This could be partly due to the front passenger position, where the subject was sitting passively. As the driver, the subject was actively controlling the vehicle.

When comparing the seating systems, the wheelchair transmitted at least twice as much longitudinal and total accelerations as the OEM seat during the acceleration and deceleration maneuvers. During the deceleration maneuvers, the wheelchair transmitted approximately four times more lateral and total RMS acceleration than the OEM seat. The wheelchair's higher transmission makes it a less suitable seat than the OEM seat because it creates a more dynamic environment in which the seated individual must stabilize himself.

CONCLUSION

This project was a preliminary study. An evaluation of the experimental design and logistics would benefit further research in this area. The maneuvers performed were chosen to represent common driving situations. Each maneuver was examined in terms of total acceleration and acceleration along the primary linear axis. Future research should examine not only linear accelerations, but rotational accelerations as well. The roll and pitch of a vehicle will have an effect on the linear accelerations experienced by both the vehicle and the subject, and these effects need to be evaluated.

The analysis of variance of the vehicle dynamics showed that difference in the vehicle accelerations in different positions within the vehicle can be established with four or five trial measures per case in spite of the large variation of the vehicle acceleration for each maneuver. The effects of speed are not so pronounced, and a greater number of trials would be necessary to quantify differences based on the speed of a maneuver. Future experiments that are designed to quantify subject response or differences in vehicle dynamics based on speed must use a much larger number of repeated measures than were used in the present study. Both a larger number of subjects and a greater number of trials per subject would have supported a more rigorous analysis of the data and produced more definitive results. Characteristics of the OEM seat and wheelchair could be more clearly defined in terms of transmission of acceleration to the subject.

The accelerations experienced by a person in a modified van were found to be dependent on both the position within the vehicle and the seat on which a person was seated. The results of this study confirm previous clinical belief that driving from an OEM seat has advantages over driving from a wheelchair. The OEM seat dampens accelerations and provides a more stable seat. Accelerations in the rear passenger area of the van were greater than in the driver area, while accelerations in the front passenger area were similar to the driver area. This result potentially impacts research that uses van passengers instead of drivers as subjects. All of the data in this study were taken in the same vehicle. Further research should use vehicles with different modifications to determine the effects of individual modifications on the vehicle dynamics.

This project was designed to begin to define the complex dynamic environment within a modified van. This environment affects the functional ability of a person with a disability, and a clearer understanding of it will permit better research and clinical practice in evaluating the driving ability of persons with disabilities. Driving is a complex interaction of physical and cognitive components, and current clinical practices evaluate driving ability based on physical abilities such as range of motion, brake reaction time, and steering strength. These abilities either should be measured in a dynamic environment, or a correlation between static and dynamic measures of these abilities must be found. Performance in the dynamic vehicle environment should be measured with the goal of providing a seating and positioning environment that maximizes functional abilities while driving.

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END NOTES

[1] Kistler 8634B5 accelerometers, Kistler Corporation, Amherst, New York.
[2] Optim Electronics, Germantown, Maryland.
[3] PCB Piezotronics, Depew, New York.
[4] Creative Controls, Inc., Warren, Michigan.
[5] Kinedyne Corporation, Lawrence, Kansas.

REFERENCES

1. Wong J. Theory of ground vehicles. New York: John Wiley and Sons, 1978.
2. Conley PA. Lateral and directional stability of vehicles modified for the physically challenged (Thesis). Charlottesville, Virginia: University of Virginia, 1993.
3. Mercer W, Billings JR. Assessment of a transportable mobility aid in severe driving conditions—an exploratory test. Ministry of Transportation, Ontario, 1990.
4. Canadian Standards Association. Motor vehicles for the transportation of persons with physical disabilities. CAN/CSA-0409-92. Ontario: Ministry of Transportation, 1993.
5. Linder G. Mechanical vibration effects on human beings. J Aero Med 1962:939–49.