Aid for Training and Evaluation of Handicapped Drivers

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Abstract

An indoor driver-evaluator and trainer-aid vehicle, developed to quantify students' ability and progress in learning to drive, is described. In general, the instrumentation for each control was built to measure operating force and elapsed time. The system consists of functional ignition and gear shift control, instrumented steering wheel, hand controls for brake and acceleration, and elapsed response time meters for each control. The controls allow the major driving functions to be evaluated in their interactive mode and the subjects to be taught using variable mechanical resistance elements. Pilot tests were made on nine tetraplegic subjects, spaced over a 4-week period for a subject. Evaluation results by the third test agreed with road evaluation for all six of the subjects who thus far have attempted licensing examinations.

Introduction

Through technology, persons with severe disability have been able to achieve mobility independence. An important measure of their independence is the ability to drive a personal licensed vehicle (automobile, van, or truck) (1, 2).

The Occupational Therapy Department at Woodrow Wilson Rehabilitation Center has been evaluating drivers for several years. All persons requiring medical authorization for driving are being evaluated. Many disabilities are involved. In evaluation, those persons with partial or complete quadriplegia (C-5 or below) requiring hand controls have become a particular challenge. The Keystone Vision Equipment, the AAA Driver Education System, and the Aetna Drivotrainer Simulator are used to evaluate clients. Reaction time and night vision are easily tested, but the Drivotrainer had to be modified to accommodate driving from a wheelchair. Recently, the evaluation program has been upgraded by the addition of an occupational therapist as a driver-education instructor who is also an evaluator and trainer. Fifty percent of her time is spent providing on-the-road evaluation and training for the severely disabled clients.

Although these tools are alternatives, and adequate for some clients, they did not provide enough information to predict the abilities of the more severely disabled clients such as the quadriplegic. The simulator, although more interactive than the others, became more useful as an exercise device rather than an evaluation tool. In particular, the above equipment failed to evaluate the simultaneous functions required by "on the road" driving. A new system was needed which would allow the quantification of the major physical variables of driving functions in their interactive mode. In addition to evaluation, the instrumentation would have to be capable of monitoring patient progress.

The resulting design criteria called for (i) a realistic method of testing and monitoring driver performance in braking, steering and acceleration, (ii) training within the spatial restrictions of the driver compartment, and (iii) provision of visual or auditory feedback during testing and training.

Following these criteria, the instrumentation should provide the guidance to establish levels of human performance necessary to permit a severely disabled individual to operate a personal licensed vehicle safely.

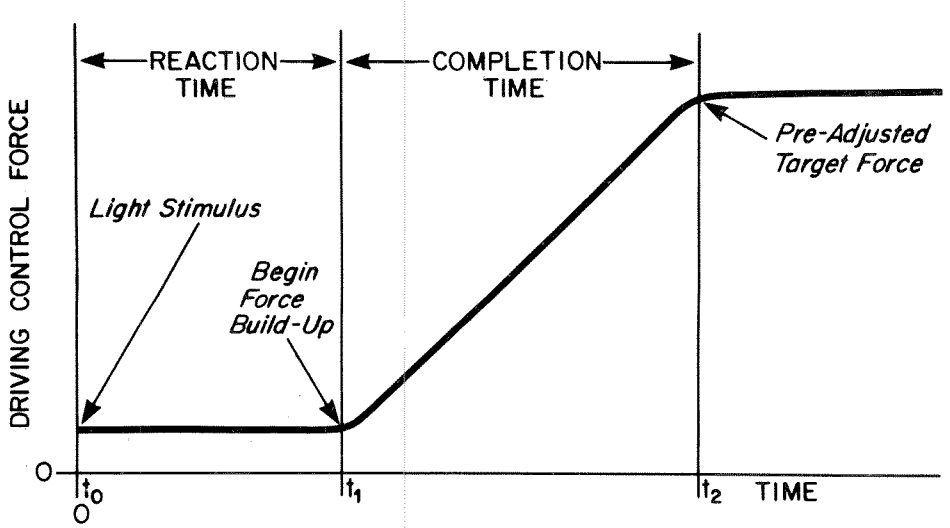

FIGURE 1.
Idealized force-response curve generated by the driver in the course of a driving task.

Controls and Instrumentation

During vehicle operation, the driver's ability to apply the necessary forces to accelerate, to brake, and to steer are not sufficient by themselves as evaluative tools. The completion of any of these driving tasks within a time interval and the ability to maintain a force level over that interval are fundamental to proper handling of the vehicle. The basis of our instrumentation is the simultaneous measurement of exerted force and duration, since driving relies strongly on the interdependence of control force, displacement, and timing.

Force monitoring of the driver's use of the vehicle controls indicates the course from onset to completion of the driving task. An idealized force/response curve as it is experienced in the acts of braking, steering, or other control tasks is shown on Figure 1. The time from a visual stimulus (at t_0) to the beginning of force build up (at t_1) is a well-defined measure of the initial reaction time ($RT=t_1-t_0$). The end point is taken when the pre-adjusted target force is reached. The time to this end point (t_2) is that for reaction plus complete force build up, and the difference is the measure of the task completion time ($CT=t_2-t_1$).

The instrumented controls were installed in an A.M.C. Pacer[a] located indoors and adapted with push-right angle pull (Gresham Slimline) hand controls and interchangeable steering adapters (Steering ball, V-grip, and wrist stabilizer adapter). An overview of the system is shown on Figure 2. The engine and automatic transmission were removed and the steering system was disconnected from the wheels, allowing space for modifications. The speedometer was modified to be controlled by a D-C motor drive, and the speed indicator was controlled from the accelerator pedal. A tri-color traffic light simulator, positioned on the front hood of the car and controlled by the tester, was added to initiate the testing sequences. Also visible on the front hood is a pressure meter, to indicate the force, in pounds, applied to the brake pedal. The implemented controls are enabled by the modified key-activated ignition system (S1) while movement of the gear shift from N to D closing switch S-2 as shown in Figure 3, is used to energize the speedometer motor through the accelerator potentiometer R1.

The task of braking involves two phases, reaction and completion. The time from the appearance of the visual stimulus to the initiation of the brake application is the reaction time. The completion time spans the period from initiation of braking to achievement of a pre-set braking force. Timers to measure these two task phases, in tenths of seconds, have been installed in the car. The reaction timer is started by the appearance of the red light controlled by the therapist at switch S_4, which is the stimulus to slow or brake the car. This counter is stopped by the initiation of braking via the brake relay K_2 through activation of brake pedal S_8. Switch S_4, held in the therapist's hand, is located out of the client's vision. To measure the completion time, there is another timer, which commences counting when braking has been initiated. The completion timer is "stopped" when the variable pre-adjusted force level on the hydraulic pressure switch S_9 is attained. This corresponds to applying a specific level of force at the brake pedal. For example when the hydraulic pressure switch is set at 200 psi, the cutoff pedal force is 40 pounds. This pedal force is registered on a meter on the front hood of the car.

Using the mode selector switch S_7, the tester can evaluate the time required for a complete turn of the steering wheel in either direction. When the steering wheel is rotated from the zero position, S_5 closes and the reaction timer starts.

[a]The Woodrow Wilson Rehabilitation Center gratefully acknowledges the American Motors Corporation's donation of this automobile used in the program.

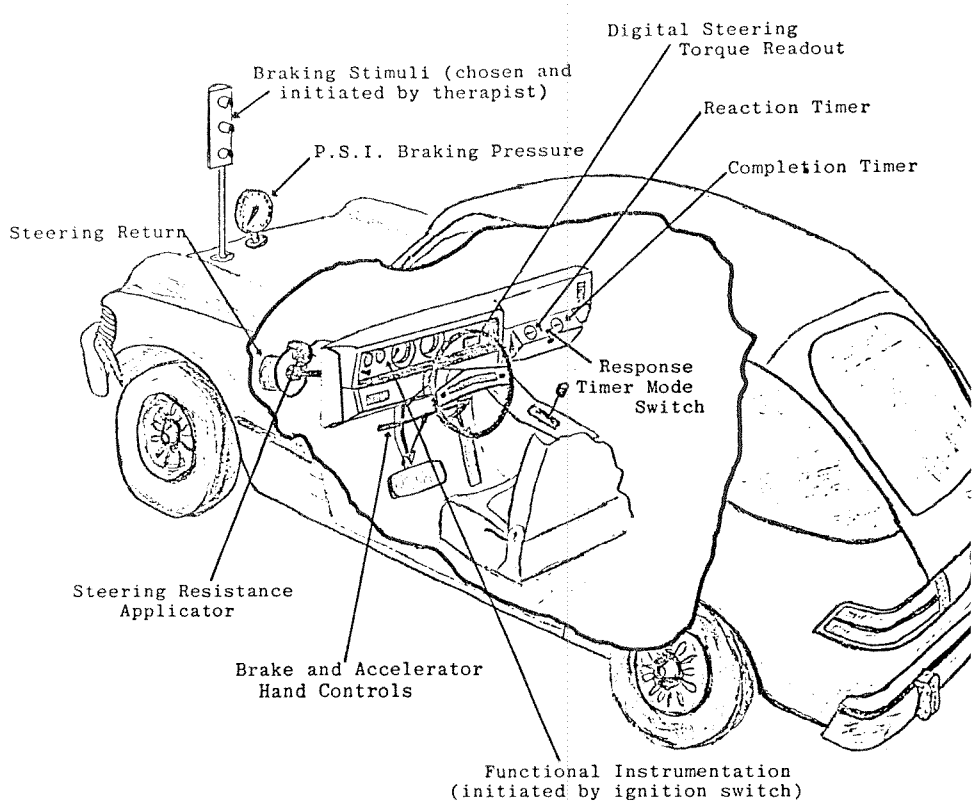

FIGURE 2.
The instrumented driver evaluator-trainer aid vehicle used for assessment of handicapped driver performance.

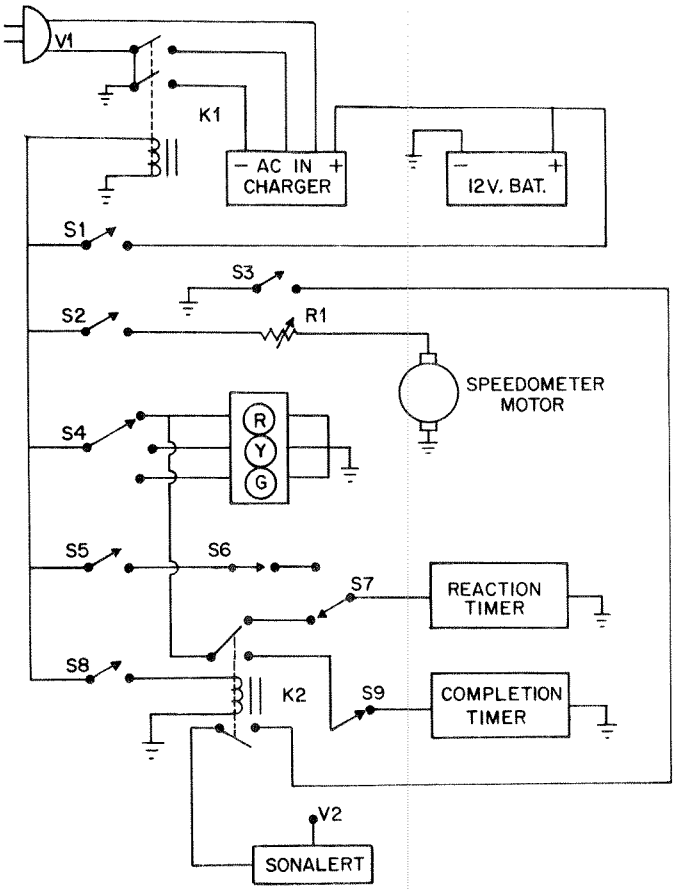

FIGURE 3.
Instrumented driver evaluator-trainer aid. Switches and relays are shown in their normal positions.
V1: 110 V a c power
V2: 4.5 V Battery
R1: Accelerator rheostat
K1: Ignition relay
K2: Brake relay
S1: Ignition switch
S2: Gearshift switch
S3: Accelerator pedal switch
S4: Stimulus selector switch
S5: Initiated steering switch
S6: Steering completion switch
S7: Mode select switch
S8: Brake pedal switch
S9: Hydraulic pressure switch

Completion of a 360 degree steering wheel turn then stops the timer by opening S_6. The tester is also able to assess the potential driver's ability to maintain constant equivalent speeds, utilizing the functional speedometer of the auto.

The potential driver's performance at steering can be evaluated by an added friction-drag torque meter. With a mechanical resistance, adjusted by the therapist on the steering column, the required steering torque applied by the driver can be increased or decreased. Visual display of the applied torque level has not been implemented on the system.

Since a common difficulty in learning to drive with push-right angle pull hand controls is the inadvertent dual application of brake and throttle, an error warning has been included to indicate when this situation occurs. When both the accelerator and brake pedals are simultaneously depressed (S_3 and S_8 are both closed), the circuit to the Sonalert ™ is completed and the audio alarm is sounded. Relays, battery, and other instruments are located under the hood. The mode selector, timers and Sonalert were placed in the glove compartment for easy access by the therapist.

Mode of Operation

Orientation, evaluation, further driving training, and supportive therapy if necessary, are the sequential elements of the training program utilizing this instrumentation.

After appropriate transfer into the auto and proper positioning with application of seat belts (activities which act as screening procedures in themselves), the driver was given a short preliminary orientation to the car. This procedure involved acquainting the driver with the ignition, accelerator, brake, and steering controls. Orientation was followed by a primary test of base-time assessment of driver performance given in a sequence:

1. The ability to maintain constant speed at 40 and 50 mph;
2. The reaction time and completion time involved in braking after the appearance of the red cue; and
3. The time required for a complete turn in either direction.

This testing sequence was performed on three occasions within a 4-week period in an attempt to establish the effectiveness of the system. Each occasion was separated by 7–10 days, the variability being introduced by driver illness, and other delays. At the end of the testing period, the clients were again evaluated for their isolated braking performance simulated at 40 and 50 mph. Throughout the testing period, all of the clients were undergoing occupational and physical therapy. It should be noted that this Driver Evaluator-Trainer aid is limited to evaluation of physical capability and it was not designed to measure mentation, perception, and cognition which are also important factors in safety and good driving performance.

Results

A small pilot series of 9 clients with traumatic tetraplegia of 5 to 41 months duration was tested. The injury levels represented were: 3 clients with C-5-6, 2 with C-6, 3 with C-7 and 1 client with C-8 level of injury.

Preliminary data showed that brake reaction times for all clients were near or below the mean normal value of

0.75 sec given by the National Safety Council (3). Reaction times, as a function of injury level for simulated 40 mph speed (Fig. 4) indicate only a weak dependence of the brake reaction time on the level of injury. On the other hand, brake completion time (as shown in Table 1) confirms the suspicion that it is a more meaningful indicator of driving capability. For Table 1 a target brake pedal force of 40 lb was selected from "on the road" tests with similar cars at 40 and 50 mph. This 40 lb brake pedal force was found to be adequate to stop the car within the braking distance prescribed by the National Safety Council (3) at either speed. The results tabulated by injury level affirm that the brake completion time is slower—as either elbow extension or shoulder rotation or both are diminished to "fair" or poorer values.

Optimal steering performance has also been evaluated for a complete left and right turn of the steering wheel with the rating of the corresponding movement. A group of 10 non-handicapped drivers were tested, each several times, and the less than 1.1 sec average turning time they produced was accepted as the control value. Similar results are shown in Table 2 for most of the patients tested, using plain steering wheel if possible or a knob if necessary. Seven of the clients showed turning performance times of 1.1 sec or less when good-to-normal shoulder function was demonstrated. Diminished shoulder function resulted in longer turning time.

How well the system can predict if an individual will be licensed is illustrated by Table 3. The results of the isolated braking and steering tests for each occasion have been converted to "ready" or "not ready" on the basis of the individual's performance. "Ready" denotes a reaction time of 0.4–0.8 sec, the ability to apply 40 lb of force within 2.5 sec, and the time for a complete turn within 1.1 sec. "Not ready" denotes a poorer performance on these tests. The results of the client's on-the-road evaluations, if conducted, have also been included. For three of the six cases in which road tests have been given, there is agreement between the results of tests on occasion one and the road evaluation. With the second test, the correlation exists for a different three of the six clients. By test occasion number three, the results of the tests agree with the road evaluations for all six cases. Thus the ability of this new evaluation tool to predict driver performance appears to be optimal after three test occasions, which in this series were spaced over a 4-week period of continuing therapy.

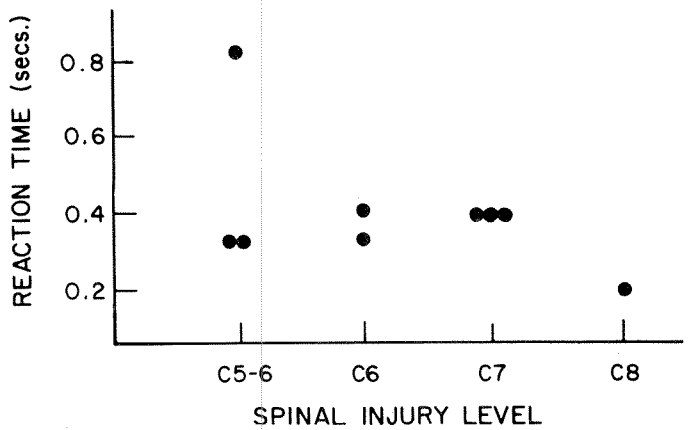

FIGURE 4.
Brake reaction time as a function of spinal cord injury level.

Conclusion

An efficient use of this system relies on the services of the therapist and on-the-road training, as well as the dual nature of the system as evaluator and trainer. It is recommended that this system be used for primary screening to access base-line performance levels, and to determine what muscles/functions need strengthening or substitution. Then, with therapy and repeated use of the testing system, it is recommended that the client be taken on the road for evaluation when he is able to apply 40 pounds of force to the brake within 2 seconds and complete a turn within 1.1 seconds. These specifications are tighter (more conservative) than the minimum conditions found earlier for the control of similar cars. An on-the-road evaluation provides the necessary performance stimuli which are required for driving progress. The indoor system could then be used to monitor further task progress or indicate therapy requirements, while on-the-road training continues.

References

1. Gurgold GD and Harden DH: Assessing the driving potential of the handicapped. Am J Occ Ther 32(1):41–47, 1978.
2. Long CH: Handicapped driver, a national symposium. J of Rehab 40:34–38, 1974.
3. Defensive Driver's Manual: 6th Edition, National Safety Council, 1971.

TABLE 1.
Isolated braking completion times and joint function by levels of spinal injury, at Occasion 3.

Client No.	Completion time (Sec.) 50 MPH	40 MPH	Target pedal force achieved (lb)	Shoulder rotation grade	Elbow extension grade	Injury level
9	0.4	0.4	40	Good−	Good −	C8
8	0.5	0.5	40	Good	Good	C7
7	0.5	0.5	40	Fair	Normal	C7
1	0.8	0.4	40	Fair +	Poor	C5–6
6	0.9	0.8	40	Good +	Fair +	C7
5	1.6	1.9	40	Good	Zero	C6
4	2.0	2.3	40	Normal	Poor	C6
3	2.2	4.4	25	Good −	Zero	C5–6
2	—	5.6	35	Poor −	Zero	C5–6

TABLE 2.
Steering performance and muscle function by levels of spinal injury, at Occasion #3.

CLIENT	COMPLETE TURN time (sec)		MUSCLE				
No.	Left	Right	Ant. deltoid	Post. deltoid	Pector. major	Bicepts and brachiorad.	INJURY LEVEL
9	0.7	0.7	G+	G+	G+	G+	C8
8	0.8	0.7	G	G	G	G+	C7
5	0.8	0.9	G	G	G−	G−N	C7
7	1.0	1.0	N	N	N	N	C7
6	1.0	1.1	F+	G+	G+	G+	C7
1	1.1	1.0	G+	G+	G+	G+	C5-6
4	1.1	1.0	N	N	N	N	C6
3	1.4	1.4	G−	G−	G−	G	C5-6
2	3.2	5.4	F−	F	F−	G	C5-6

TABLE 3.
Evaluation of client's driving potential: isolated steering and braking tests

Client No.	Occs. #1	Occs. #2	Occs. #3	On-the-Road
9	Ready	Ready	Ready	No road test
8	Not Ready	Not Ready	Ready	**Licensed**
7	Not Ready	Not Ready	Ready	No road test
1	Not Ready	Not Ready	Ready	**Licensed**
6	Not Ready	Not Ready	Ready	No road test
5	Ready	Not Ready	Ready	**Licensed**
4	Not Ready	Not Ready	Ready	**Licensed**
3	Not Ready	Not Ready	Not Ready	Not Ready
2	Not Ready	Not Ready	Not Ready	Not Ready