

A Simulator for Objectively Evaluating Prospective Drivers of the Scott Van^a

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ABSTRACT

A simple simulator for evaluating the physical capabilities of severely handicapped prospective drivers was developed and evaluated. The simulator presents a two-dimensional tracking task to be carried out using the driving controls of the Scott van, which is a uni-lever servo-controlled vehicle designed for the severely impaired. Twenty-five able-bodied subjects were tested on the simulator and 13 of them were then given driving tests in a Scott van. Simulator RMS tracking error and the number of traffic cones knocked down were the respective performance measures for these tests. Nine severely disabled subjects were then tested in the simulator and in driving tests in the van. In order to compare the simulator performances of the handicapped subjects with their driving performances, their performance scores were all converted to T-scores. The T-score transformed the performance of these subjects into scores having as a common reference the performances of the able-bodied subjects.

Simulator T-scores for the handicapped subjects reflected large variations in their tracking abilities due to differences in their functional capabilities. Most importantly, in the authors' opinion, was the fact that the simulator T-scores of the handicapped subjects correlated very well with their driving performance T-scores. This type of simulator therefore appears to be a valuable tool for providing objective and quantitative data for evaluating severely handicapped prospective drivers.

INTRODUCTION

The ability of handicapped people to drive personal vehicles safely is largely dependent upon physical capabilities such as strength, range of motion, speed of movement, coordination, reaction time, and endurance. Although visual and perceptual functions are also needed for driving, muscular strength and control are fundamental to the driving prospects of handicapped individuals. Without the physical ability to control the vehicle properly, a driving candidate has no chance of achieving independent mobility.

Although driver training programs for the handicapped have generally performed well in facilitating access to independent transportation for handicapped individuals, current methods and procedures for evaluating physical capabilities are lacking in several respects. The heavy reliance on the subjective judgments of experienced evaluators leaves much to the discretion of the evaluator, creating at least the potential for inconsistency and inaccuracy. The need for more objective and stan-

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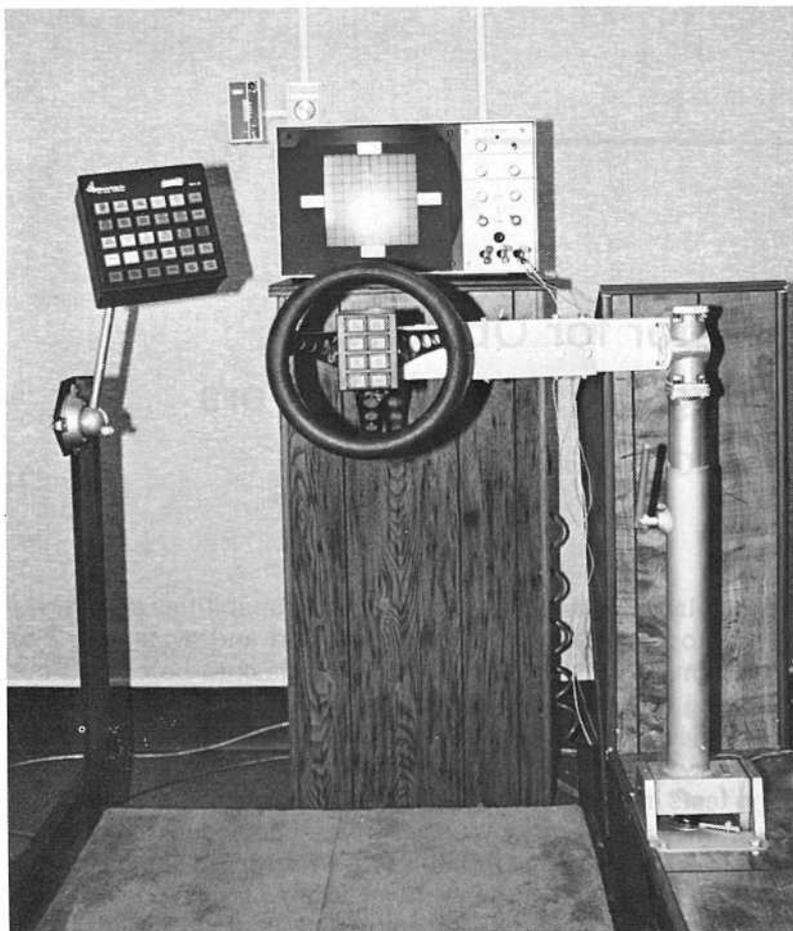


FIGURE 1

The driving controls of the simulator (left) and of the Scott van (above). The display scope of the simulator provided the visual input for a two-dimensional tracking task that required driving candidates to reproduce the control motions needed to drive the van.

tions, the evaluator must often interpret the relationship between performance in a laboratory task and its meaning in terms of the driving task. Such laboratory tests typically measure abilities such as strength, range of motion, and reaction time separately, whereas driving involves complex combinations of these abilities.

The need to evaluate the composite physical capabilities of driving candidates has led to the use of driving simulators, but most of these are still not able to indicate potential driving capabilities accurately. As Reger et al. (4), have noted, conventional driver education simulators equipped with hand controls are more useful as exercise devices than as evaluation tools. Those simulators that have proved useful for evaluating and training handicapped drivers are complex and expensive (5), and are therefore limited in availability.

Another common means of assessing the effects of the simultaneous interactions between separate physical abilities is the use of actual driving attempts as an evaluation tool (6). Again, the judgment of the evaluator is the major factor in estimating driving prospects. Another drawback of behind-the-wheel evaluations is the inherent need for a wide variety of vehicles if you must evaluate a wide range of people having different functional capabilities. The high cost of modified vehi-

ly, initial driving attempts also involve apprehension (and a certain degree of actual danger) because of the uncertain physical capabilities of the prospective driver.

The deficiencies of existing evaluation procedures are compounded for the severely handicapped, who often need extensively modified servocontrolled vehicles. The higher costs of such vehicles further restrict their availability for evaluation purposes. Relying on judgments that are largely subjective is also potentially either unfair or dangerous for the severely impaired, because the match between their limited capabilities and the specific requirements of the appropriate vehicle is very delicate in many cases.

In an effort to increase the objectivity, availability, and safety of driving evaluations for the severely handicapped, we have developed a low cost simulator of the Scott van^c. The Scott van is a uni-lever servocontrolled van designed for people disabled by poliomyelitis, multiple sclerosis, muscular dystrophy, or spinal cord injury at the C4, C5, or C6 levels (7). The three primary driving functions, accelerating, braking, and steering, are controlled by manipulating either a 9-inch-diameter steering wheel or a one-arm tri-post device. The simulator and van used in this research were both equipped with the mini-steering wheel,

objectively measure a driving candidate's ability to properly manipulate the driving control and execute the complex motions required in actual driving. Rather than replacing an experienced evaluator, the simulator is intended to provide him or her with more reliable information upon which an objective decision could be made about a handicapped person's driving potential. The simulator is also intended to be as simple and inexpensive as possible, in order to maximize its potential availability for clinical use.

It was recognized that simulator testing cannot always replace actual driving tests in obtaining a definitive assessment of driving potential. The highly complex visual scene, and the inertial forces on the driver, are just two of the many characteristics of actual driving that probably cannot be authentically reproduced in the laboratory. However, the simulator seems to be a tool that can expand the laboratory evaluation to include a quantitative assessment of a candidate's ability to operate the driving controls as required in certain actual driving situations. Such a simulator would enable driving centers to offer more complete evaluation services without having to purchase additional costly servocontrolled vehicles.

The remainder of this paper describes a simulator that can provide an objective assessment of physically handicapped driving candidates, and describes the experiments that were conducted to compare this simulator's results with actual behind-the-wheel driving performances.

^cThe Scott van is produced by Mobility Engineering and Development (M.E.D.).

SIMULATOR DESCRIPTION

The main body of the simulator consists of a replica of the driving control of the Scott van (Fig. 1). The van is steered by turning the 9-inch steering wheel which can be turned as much as 90° clockwise or counterclockwise. The vertical post to which the steering wheel is attached is hinged at the base; pushing the steering wheel forward depresses the accelerator, and pulling it backward applies the brakes. Total travel fore-and-aft is approximately 6 inches (15 cm). The replica of the driving control was purchased from Mobility Engineering and Development, Inc., manufacturer of the Scott van. The resistive forces for steering, braking, and accelerating are provided by a system of springs and hydraulic valves within the simulator. These forces were set at approximately one pound (4.4 N) for steering, 2 pounds (8.9 N) for braking, and 4 to 5 pounds (17.8–22.2 N) for full acceleration—to mimic the forces needed to drive the actual van. The ranges of control motions were also matched with those of the van.

A two-dimensional tracking task was chosen as the simulation method because of its success in similar applications. A typical tracking task consists of a screen presenting a target symbol that moves about in some prescribed fashion and a response symbol that responds to the subject's manipulation of a controller. In the pursuit tracking task used for the simulator, the subject attempts to follow the target as accurately as possible by properly manipulating the controller. (One-dimensional tracking tasks have been success-

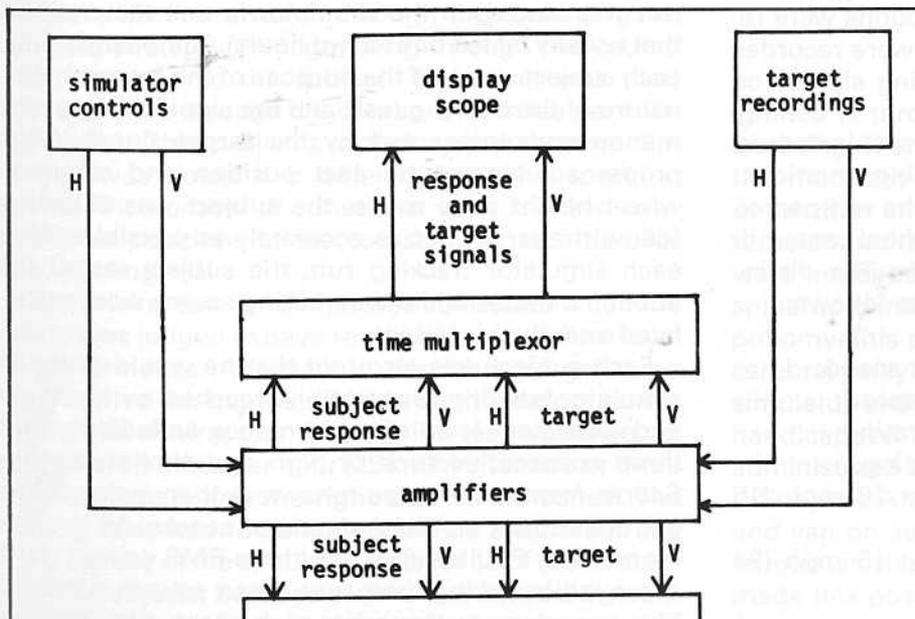


FIGURE 2

A functional block diagram of the simulator components.

fully used by others to evaluate neurological functions in people with multiple sclerosis and Parkinson's disease (8) and to monitor the rehabilitation progress of stroke victims (9).)

The display scope for the tracking task (Fig. 1) was 6 in. × 6 in. (15 cm × 15 cm) with the center of the screen near eye level and about 30 inches (76 cm) in front of the subject. To display simultaneously the target and response signals as dots, the vertical and horizontal components of the signals were time multiplexed at 100 Hz. The functional relationships between the components of the simulator are shown in Figure 2.

The simulator "driver's" response signals are generated from two linear displacement potentiometers mounted on the base plate of the vertical post of the driving controls. One potentiometer monitors steering movements and the other detects throttling or braking motions. Steering responses produce horizontal movements of the response dot, while braking or accelerating actions produce vertical movements of the same dot. Pushing forward on the steering wheel moves the response dot upward on the screen, and pulling back on the wheel moves the dot down. The response dot is centered on the screen when the steering wheel is centered and the vertical post is in its neutral position.

The target signal for the tracking task was provided by a cassette tape played on a TEAC R-61 data recorder. The signals for the tape were obtained by mounting the two potentiometers on the base plate of the driving controls of an actual van exactly as they are mounted on the simulator. The van was then driven through a series of basic driving maneuvers by a skilled driver familiar with the Scott van. The potentiometer outputs generated in response to his driving actions were recorded. Throttling and braking signals were recorded on one channel of the recorder, steering signals on another.

Seven basic driving maneuvers were selected as being representative of a variety of driving situations. Each maneuver begins and ends with the van parked and fully braked and with the steering wheel centered. Each maneuver lasts 30 to 35 seconds. The distinguishing feature of each maneuver is as follows:

- Maneuver 1—straight ahead driving;
- Maneuver 2—right turn at a constant speed;
- Maneuver 3—left turn at a constant speed;
- Maneuver 4—right turn while accelerating;
- Maneuver 5—left turn while accelerating;
- Maneuver 6—serpentine (S-curve) at 10 mph (16 km/h); and
- Maneuver 7—serpentine (S-curve) at 15 mph (24 km/h).

The maximum speed attained during maneuvers 1

intersection. The layout of the serpentine course for maneuvers 6 and 7 is shown in Figure 3. The signals recorded during the seven basic maneuvers were then used to construct the target tape, which contained a series of tracking runs. These runs, which lasted about 4-1/2 minutes each, consisted of all seven maneuvers in various orders.

As shown in the block diagram of Figure 2, the target and response signals were connected to a digital computer for scoring. The analog signals were sampled 10 times a second, converted into digital form, and stored. The sampling rate was considered sufficient since a spectral analysis of the target and response signals revealed no significant components above 2 Hz. The tracking task was scored by calculating the root-mean-square (RMS) error between the target and response signals. The RMS error was used because it is a widely recommended measure of tracking accuracy (10). The computer calculated the RMS error using the following formula:

$$\text{RMS error} = \sqrt{\frac{1}{N} \sum_{i=1}^N E_i^2}$$

where E_i is the error at each sample point and N is the number of sample points.

EXPERIMENTAL PROCEDURES

Twenty-five able-bodied subjects were tested on the simulator to provide reference data against which the handicapped subjects would be compared. Each subject was tested on the simulator in one test session that usually lasted one to two hours. At the beginning, each subject was told the purpose of the research, the nature of the tracking task, and the significance of the maneuvers represented by the target signal. After proper adjustments in seat position and steering-wheel height were made, the subject was asked to follow the target dot as accurately as possible. After each simulator tracking run, the subject rested for about 5 minutes while the tracking scores were calculated and shown to him.

Each subject was also told that he would perform simulator tracking runs until he reached a maximum and consistent level of performance as indicated by three consecutive runs of high and similar quality. Scores from those three runs were then averaged to get the subject's official simulator scores. As recommended by Poulton (10), the three RMS scores were averaged by taking their root mean square average. This was done by squaring each score, dividing the

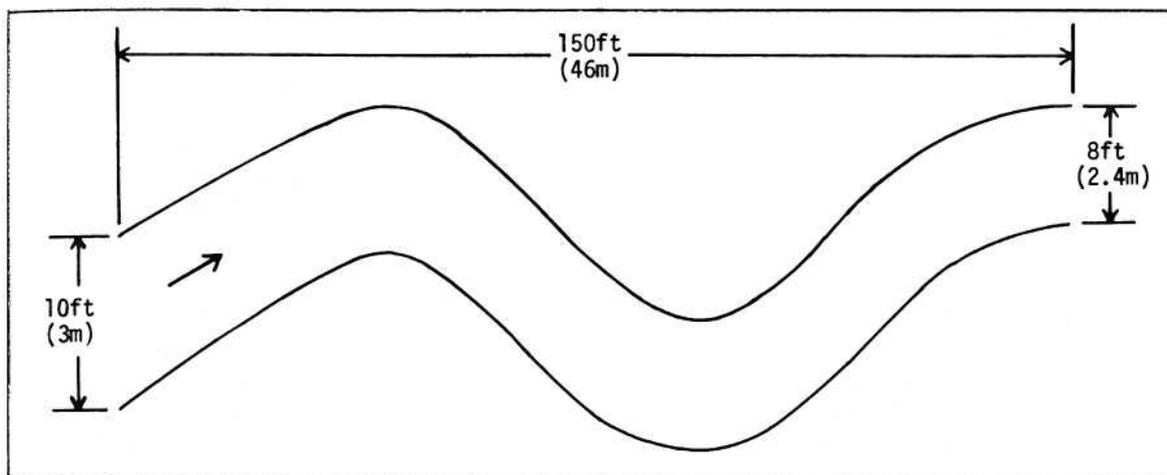


FIGURE 3. Schematic diagram of the serpentine driving course used to generate part of the target signal for the simulator tracking task. The course was also used for driving tests.

Thirteen of the able-bodied subjects were also given driving tests. Only two of the seven driving maneuvers were used for the driving tests because of the limited time and availability of the Scott van used in this research. Maneuvers 6 and 7, the two serpentine (or S-shaped) maneuvers, were selected for the driving tests, since they have been successfully used by others (11) to measure driving ability, and because these maneuvers were amenable to objective scoring.

Fifty rubber traffic cones were set up on an empty parking lot to form the serpentine course (Fig. 3) as had been done earlier to produce the target recording. Before driving through the course, each subject was properly positioned in the driving station of the van. Ten to twenty minutes were then spent driving the van in an empty parking lot for orientation and practice. Two or three practice runs were then made with the subject driving alongside the cones so he could get an idea of the contour and rhythm of the course.

Before his first attempt through the cones (Fig. 4), the best strategy for negotiating through the course was explained to the subject. The driver was then asked to drive through the course at 10 miles per hour (16 km/h). The subject's actual speed through the course was noted if it differed from the specified speed. The number of cones that were knocked over and their positions in the course were recorded for each driving trial.

The driving test at 10 mph was concluded when the driver was judged to have reached his maximum level of performance. An attempt was made to get three consecutive driving trials of this quality before terminating the driving test. The driving test was then repeated at 15 miles per hour (25 km/h) after two or three practice runs along the right side of the cones. The driving tests had to be conducted on a different day from the day of the simulator tests for 12 of the 13 able-bodied subjects, because of time and availability constraints. The driving session usually lasted 1 to 1-1/2



FIGURE 4
A subject driving the Scott van through the serpentine course lined with traffic cones.

ignated A through I) were given both the simulator tests (Fig. 5) and the driving tests. All nine were classified medically as quadriplegics, reflecting a total loss of function in their lower limbs plus a partial loss of function in their upper limbs. Most of these subjects were impaired as a result of traumatic injury to the spinal cord in the cervical region. Subject E was a post-poliomyelitis patient, and subjects F and G both had cerebral palsy resulting in considerable spasticity. The simulator and driving tests were administered to the handicapped subjects in the same way that it was administered to the able-bodied subjects.

Subjects A through D were tested in the simulator and van on separate days to minimize the effects of fatigue on their performances. Their local residence made this possible and convenient. The other handicapped subjects had to travel up to 70 miles each way

EXPERIMENTAL FINDINGS

The results of the simulator and driving tests for the able-bodied subjects are summarized in Table 1. The results of the simulator and driving tests for the handicapped subjects are summarized in Table 2. Subject H did not have the necessary strength to push the steering wheel forward on either the simulator or van, but was able to steer both effectively. In order for her to participate, the forces required for the simulator's accelerator were reduced from 5 to 2 pounds (22.2 to 8.9 N), and the experimenter manually helped her push the steering wheel forward during the driving tests to maintain proper van speed. Subjects F, G, and H completed the driving test for only maneuver 6 because the time available for using the van was exhausted.

In order to compare the simulator performances of the handicapped subjects with their driving performances, their performance scores were converted to T-scores. The T-scores transformed the performances of these subjects into scores having as a common reference the performances of the able-bodied sub-

jects. The T-score is defined as follows:

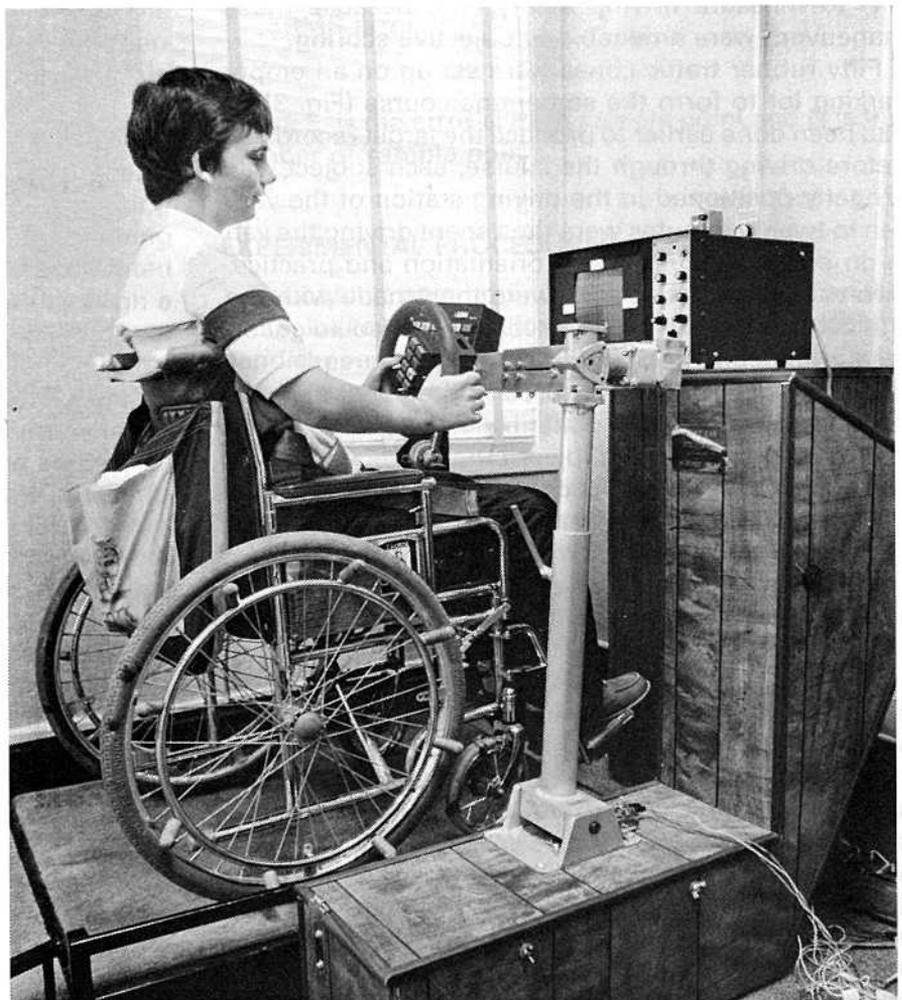
$$T\text{-score} = \left[\frac{X - \bar{X}}{S} \right] [10] + 50$$

where X is the value being converted, \bar{X} is the mean of the reference data and S is the standard deviation of the reference data. T-scores classify each value according to the number of standard deviations it is away from the mean of the reference data. A T-score of 50 corresponds to this mean, and each standard deviation that a value is above or below the mean results in 10 points being added to or subtracted from 50, respectively.

T-scores are often used for analyzing data that are assumed to come from a normally distributed population, in which case the sample mean and standard deviation completely describe the data. However, the use of T-scores here, to characterize the performances of the handicapped subjects, does not imply that the performances of the able-bodied subjects were as-

FIGURE 5

A subject performing the simulator test. At base of the driving control's vertical post can be seen a portion of the instrumentation which picks up the subject's "steering, throttling, and braking" responses to the target tracking task appearing on the oscilloscope.



DISCUSSION OF RESULTS

Two important features of the results of maneuver 6 are evident in Figure 6. First, the simulator and driving T-scores matched extremely well for 7 of 8 subjects. Only the T-scores for subject H (78 in the simulator and 128 driving the Scott van) showed a major discrepancy. This discrepancy may have been caused by alterations to the experimental procedures that allowed subject H to participate in the research. Changes were needed because this subject was unable to push the steering wheel of either the simulator or the van, and therefore could not have become a driver of the van. Including the scores of subject H, the simulator scores strongly agreed with the corresponding driving performances as reflected by a Spearman rank correlation coefficient (12) of 0.763 (significant at the $\alpha = 0.05$ level). If the scores of subject H were not included, the same correlation coefficient would be 0.696 (also significant at the $\alpha = 0.05$ level).

Second, the performance T-scores in Figure 6 clearly divided the handicapped subjects into two categories: those who performed similarly to the able-bodied subjects, and those whose performance was much poorer. (Subjects F and G composed the latter group.) The inconsistent scores of subject H placed her in both categories as indicated by her poor performance driving but relatively good performance in the simulator. Other subjects (B, E, and I), with simulator T-scores near that of subject H, drove well in the Scott van, as indicated by their T-scores. The remaining subjects (A, C, and D) also scored very well for both tests with reference to the able-bodied subjects.

As indicated in Figure 6, the simulator and driving performance T-scores of subject I were somewhat different (71 vs. 38), but this difference was considerably smaller than the 50 point difference for subject H. Since subject I's scores for simulator and driving performances were within 2 standard deviations of the respective performances of the able-bodied subjects, subject I was grouped together with the subjects who performed in a manner similar to the able-bodied subjects.

In short, the results for maneuver 6 showed that the simulator provided performance indices that not only corresponded well with actual driving performances but also discriminated between subjects who performed well and those who performed poorly with reference to the able-bodied subjects.

The simulator T-scores for maneuver 7 (Fig. 7) also correlated extremely well with the corresponding driving T-scores as indicated by a Spearman rank correlation coefficient of 0.943 (significant at the $\alpha = 0.05$ level) between the T-scores of the six subjects who

handicapped subjects who generally obtained higher T-scores on this maneuver than they did on the slower maneuver. Subjects E and I were particularly affected by the greater difficulty of maneuver 7, as manifested in the relatively sharp increases in their simulator and driving T-scores over those for maneuver 6. The simulator T-scores for subjects F, G, and H are also higher for maneuver 7, exceeding 100 for all three.

The greater difficulty of maneuver 7 revealed another important feature of the simulator. The higher vehicle speed for this maneuver required different combinations of strength, range of motion, and particularly speed of movement from the subjects. Since both the simulator and driving results for maneuver 7 reflected its increased difficulty, the simulator appeared to be quite sensitive to changes in the subjects' abilities to produce the more difficult combinations of physical movements successfully. In particular, subjects E and I appeared to lack the specific combinations of abilities needed for maneuver 7, although they seemed to possess the combinations of abilities needed for maneuver 6. The simulator therefore appears capable of detecting even small perturbations in each driving candidate's ability to produce the control motions required in different driving situations.

No simulation is ever perfect. We certainly recognize that the simulator was validated by driving tests using only the two serpentine maneuvers, which were low-speed driving tasks. We also recognize that some of the subjects were not completely trained to drive the van prior to data collection and that the simplistic visual display of the simulator lacked the perceptual realism of actual driving. With regard to these apparent limitations, the following comments apply:

1. Driving performance over the serpentine course correlates well with actual driving performance in a variety of traffic situations (11).

2. The simplicity of the driving course and the low speed used reduced the amount of training required to handle the Scott van under the testing conditions. The possibility of inadequate training was thus mitigated.

3. The lack of perceptual realism in the tracking display does not reduce the simulator's validity, because the display was intended strictly to motivate the subjects to reproduce the control motions needed to drive the Scott van through typical traffic situations. The simulator was designed to detect physical abilities or difficulties rather than perceptual ones.

CONCLUSIONS

The experimental results provide encouraging support for the usefulness of the simulator as an evalua-

ally confirmed by good behind-the-wheel driving performances.

The two-dimensional tracking task appears to be a very promising simulation method for evaluating severely physically handicapped persons as potential drivers of the Scott van. These findings suggest that the same simulation method is likely to be successful for other types of servocontrolled vehicles. As more and more of these vehicles become available, using relatively low-cost simulators for assessment could obviate the need for purchasing additional vehicles while still providing reliable evaluation services. ■

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