TOWARD THE DEVELOPMENT OF A COMPREHENSIVE DRIVING TEST: LOW-SPEED MANEUVERING

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The purpose of this study was to develop a battery of low-speed driving tests that could be used for preliminary screening of drivers, vehicles, and components.

A number of driving tests were developed, together with suitable performance measures. These were administered to a group of 26 subjects, and the data subjected to a factor analysis.

Six factors emerged from the analysis, with one or more tests under each. The results indicate that a test battery can be created using a small number of tests, in a relatively confined space, and without elaborate instrumentation, and still sample a number of relevant driving skill dimensions.
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ACKNOWLEDGEMENT

The work described in this report was initiated under the direction of Dr. James L. Cockrell. Mr. Barclay P. Butler carried out the background work, developed most of the tests, and laid them out on the test course. Mr. William T. Burgess supervised the data collection effort. In this he was ably assisted by Mr. Roderic H. Lowe. Dr. Michael Sivak carried out the factor analyses and assisted in preparing the final report.
INTRODUCTION

One of the goals of the University of Michigan Rehabilitation Engineering Center is to develop a means of evaluating how safely a given driver-vehicle system can operate on the public roads. As a practical matter, it is unlikely that a single test or series of tests could provide a reliable, objective measure of the type desired. But, it does seem reasonable that scorable driving tests could be used, in combination with other criteria, to assist in making this crucial determination.

The idea is not new. Tests and batteries of tests have been used for many years to evaluate drivers and vehicles. In the field of Rehabilitation Engineering, a notable example is found at Texas A&M University, where researchers have used an extensive battery of tests to evaluate everything from simple control modifications to whole vehicle systems. A review of the general approach and tests used is provided by Koppa (1979).

Adequately sampling all relevant dimensions of driving skill requires an extensive battery of tests. This often takes a great deal of space as well as time spent taking down and setting up test courses. It also means much time spent collecting data per subject, a considerable expense. Thus, there is merit in reducing the number of tests to the minimum possible. However, this requires some difficult choices. The following criteria seem especially relevant:

1. The tests should represent skills that relate to safe and effective vehicle operation.
2. The tests should tap a variety of relevant driving skills.
3. Multiple tests that measure the same skill should be avoided.
4. Finally, it is advisable to favor tests that are easy to set up and run, require little space and/or equipment, and are easy for the subject to understand.

The present study was conducted as a first step in developing the information required to meet the criteria stated above.

METHOD

Briefly, the study consisted of developing and administering a substantial battery of driving tests to a sample of subjects, and subjecting the data to a factor analysis. This is similar to the approach used by Herbert (1963), although his primary interest was in identifying psychomotor skills in the operation of trucks.

Driving Tests

The battery consisted of thirteen basic tests, several of which were run in two directions ("right" and "left"), and most of which yielded more than one performance measure. A description of each test follows:

A. GYMKHANA

This test was performed on a closed driving course approximately 0.2 miles in length. The course was defined by 10 "gates." Each gate was nine feet wide and marked by two traffic cones. A single cone placed near the first gate identified the "finish line." The course layout is represented diagrammatically in Figure 1.

Participants were driven around the test course once by the experimenter to familiarize them with the proper route. They then completed three separate runs through the course. Drivers were
Figure 1. Schematic of gymkhana course. Space between cones at each gate (9 feet) exaggerated for clarity.
instructed to negotiate the entire course as quickly as possible without touching any cones.

Criteria:

1. Time, first run.
2. Time, third run.
3. Time, total of all three runs.
4. Cones touched, total of all three runs.

B. PARALLEL PARK--IN

Figure 2 illustrates the traffic cone positions used for the parallel parking test. The parking space was 25 feet in length, defined by three cones at each end of the space. Small red flags attached to wooden sticks (50 inches in height) were placed in each cone. A standard asphalt curb formed the third side of the space. Photographs of the arrangement are provided in Figures 3 and 4.

Participants were asked to park the test vehicle in the space as quickly as possible without hitting any cones or flags. Each trial was begun with the vehicle in the same position, next to the "car" occupying the space ahead of the test space. Drivers were instructed to attempt to center the car in the space and to get as close to the curb as possible. The maneuver was performed five times by each driver.

Criteria:

1. Time, first trial.
2. Time, fifth trial.
3. Time, total of all five trials.
4. Distance to curb, first trial.
5. Distance to curb, fifth trial.
6. Distance to curb, total of all five trials.
Figure 2. Schematic of arrangement of markers for parallel parking task.
Figure 3. Photograph of arrangement of markers for parallel parking task.

Figure 4. Photograph of test car in "finish" position for parallel parking task.
C. PARALLEL PARK--OUT

After each parallel parking trial was completed, drivers were also evaluated on their ability to maneuver the test vehicle out of the space and back to the original start position. The trial started from wherever the vehicle rested in the space at the conclusion of the parallel parking maneuver.

Criteria:
1. Time, first trial.
2. Time, fifth trial.
3. Time, total of all five trials.

D. RIGHT ANGLE PARKING--IN

Traffic cones and flags, set up according to the layout shown in Figure 5, were used to define a right angle parking space and short lane perpendicular to the space. Participants were instructed to pull into the space as quickly as possible without touching any cones, starting from a position in the perpendicular lane 19 feet away from the entrance to the space. They were also instructed to pull as close to the cones marking the front of the space as possible without touching them. Figure 6 is a photograph of the test set up.

This maneuver was performed a total of six times by each driver, three times from each direction, alternating directions. "Left" or "right" refers to the side of the car on which the parking space was located as the subject approached it.

Criteria (for each direction):
1. Time, first trial.
2. Time, third trial.
3. Time, total for all three trials.
Figure 5. Schematic of arrangement of markers for right angle parking and "Y" backing maneuvers.
Figure 6. Test car being maneuvered into space for right angle parking task.
4. Distance from car bumper to marker cone, total for all three trials.

E. RIGHT ANGLE PARKING--OUT

Starting from wherever the vehicle rested from the previous right angle parking trial, participants were asked to back the vehicle out of the space and pull forward in the perpendicular lane to the starting position of the previous "in" trial. (For example, if the parking trial was begun with the vehicle facing north, the driver would back out of the space pointing the tailgate north, and then pull forward heading south.)

This maneuver was also performed a total of six times by each driver, three times from each direction, alternating directions. "Left" or "right" refers to the direction from the start position in which the vehicle was headed at the conclusion of the maneuver.

Criteria (for each direction):

1. Time, first trial.
2. Time, third trial.
3. Time, total for all three trials.

F. "Y" BACKING

The same cone/flag setup used for the right angle parking maneuvers (see Figure 5) was used for a "Y" maneuver. At the start of each maneuver, the vehicle was positioned facing away from the space in the perpendicular lane with the tailgate 19 feet from the entrance. Drivers were instructed to: (1) back into the space; (2) lightly touch the flag at the head of the space with their rear bumper; then (3) pull straight out into the perpendicular lane toward the end opposite the trial's
starting position, thus completing a "Y." Figure 7 is a photograph of the test car when backed fully into the space.

This maneuver was performed a total of four times by each driver, two times from each direction, alternating directions. "Left" or "right" refers to the side of the car on which the parking space was located at the start of the maneuver.

Criteria (for each direction):
1. Time, first trial.
2. Time, second trial.
3. Time, total for both trials.

G. STRAIGHT CONTROLLED STOP

Figure 8 illustrates the cone setup for the controlled stop maneuver. Drivers began each trial at the open end of a marked lane. They were instructed to drive down the lane at an approximate speed of 15 mph, and then stop as close to the "stop cone" as possible without touching it. Each participant was told to "ease up to the cone" rather than make a hard braking maneuver.

The maneuver was performed three times by each driver. One experimenter rode in the passenger seat to monitor the speed.

Criteria:
Total distance, car bumper to center marker cone, for all three trials.

H. SERPENTINE

The setup for this maneuver is depicted in Figure 9. Traffic cones were used to produce a symmetrical "slalom" course the driver was to traverse as quickly as possible without touching any cones. On each run
Figure 7. Test car in space for "Y" maneuver.
Figure 8. Schematic for straight stopping maneuver.
Figure 9. Schematic of serpentine maneuver.
through the test, participants had to negotiate eight 12-foot gates, making left and right maneuvers in rapid succession. Each driver completed four trial runs.

Criteria:

1. Time, first trial.
2. Time, fourth trial.
3. Time, total of all four trials.
4. Total cones displaced, all four trials.

I. FIGURE-8

Six traffic cones were set up to define the dimensions of this maneuver (see Figure 10). On each trial run, the driver completed three figure-8's in a continuous fashion. Each driver completed two trial runs.

Criteria:

1. Time, first run.
2. Time, second run.
3. Time, total of runs one and two.
4. Total cones displaced on both runs.

J. SMALL-RADIUS TURN

Cones were set up to form a 180-degree turn with a constant radius of 40 feet, and a lane width of nine feet (see Figure 11). At the beginning of each trial, the vehicle was positioned 100 feet away from the entrance to the lane. Participants were instructed to drive through the entire turn without hitting any cones, trying to maintain a constant speed of 15 mph. One experimenter rode in the vehicle to monitor speed.
Figure 10. Schematic of Figure-8 maneuver.
The maneuver was completed four times by each driver, twice as a right turn, twice as a left turn.

Criteria (for each direction):
1. Total time for both runs.
2. Total cones displaced for both runs.

K. SMALL TURN--STOP

The same layout as described for the small radius turn was used for this maneuver. Additionally, a single cone was placed in the center of the lane at the apex of the turn (see Figure 11). Participants were told to enter the lane at 15 mph but then slow down and stop as close to the "stop cone" as possible without touching it. This maneuver was performed twice from each direction.

Criteria (for each direction):
1. Total cones displaced on both runs.
2. Total distance from car bumper to stop cone on both runs.

L. LARGE-RADIUS TURN

Figure 12 shows the cone setup for this maneuver. The nine-foot lane forms a 180-degree turn with a 100-foot constant radius. Drivers were instructed to negotiate the turn at a steady speed of 20 mph. The trial sequence and the measures recorded were the same as those described for the small-radius turn.

M. LARGE TURN--STOP

The cone layout for the large-radius turn was used with an additional stop cone placed in the center of the lane at the apex of the turn. Drivers entered the lane at 20 mph and then stopped as close to
Figure 11. Schematic of small radius turn. Radius = 40', lane width = 9'.
Figure 12. Schematic of large radius turn. Radius = 100', lane width = 8'.
the stop cone as possible. The trial sequence and measures obtained were the same as those described for the Small Turn and Stop.

Test Area

All the tests just described were set up on a parking lot. The approximate dimensions of the lot were:

- South edge - 700 feet
- North edge - 800 feet
- East edge - 400 feet
- West edge - 135 feet

The area was paved in asphalt, which was in very good condition. With the exception of three light stanchions it was completely free of obstacles.

Test Vehicle

The test vehicle was a 1980 Ford LTD station wagon. It is pictured several times in the figures dealing with the driving tests.

Subjects

The subjects were licensed drivers who responded to a newspaper advertisement. They ranged from 17 to 41 years of age, although most were from 20 to 30 years of age. Twenty-seven subjects were run through the complete battery of tests. One person was found to be blind in one eye after she had started the test, and this, coupled with the fact that her overall performance was poorer than anyone else, led to her data being excluded from the analysis. Thus, the analysis was based on 26 subjects.

Procedure

The sequence of the tests was varied from subject to subject. Necessary instructions and, in some cases, demonstrations were provided
prior to each test. The entire sequence required about one-and-one-quarter hours to complete.

Data Analysis

The combination of thirteen tests and, in most cases, two or more criteria for each, resulted in a total of 58 measures. It was anticipated that many of these measures would be highly correlated and, in a first effort to reduce the number to a more manageable level, a correlation matrix was produced for the entire set. This matrix was inspected for measures which could reasonably be eliminated. For example, it was noted that first-trial, later-trial data within a given test generally correlated highly with the total score. By way of illustration, that portion of the matrix for the Gymkhana time scores is reproduced below.

<table>
<thead>
<tr>
<th>Trial 3</th>
<th>Total</th>
</tr>
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<tr>
<td>Trial 1</td>
<td>.71</td>
</tr>
<tr>
<td>Trial 3</td>
<td>.67</td>
</tr>
</tbody>
</table>

These intercorrelations were felt to be high enough so that there was no point in dealing with them separately. All other instances where separate trial data were evaluated yielded intercorrelations at least as high as those in the Gymkhana. In each case only the total score was used, based on reasoning that it should be the most reliable measure because it contained the most data.

By this process the number of measures was reduced considerably. In addition, the correlation between the right and left portions of the right-angle parking test were high enough to combine for both the in and out conditions.
A total of 24 measures remained at this point. Thirteen of these were time related, and eleven were precision (distance or cone-contact) related. Two factor analyses were conducted at this point, one on each of these two groups.

The factor analysis on the time scores yielded two factors; the precision measure analysis yielded four. The data were reviewed again at this point, seeking to eliminate tests which did not contribute strongly to one of the factors. Five such tests were dropped from the time scores, four from the distance and cone scores, reducing the total tests to fifteen. The final factor analysis was carried out on these measures.

RESULTS

Table 1 presents the varimax-rotated solutions of the factor analysis on the final fifteen measures. Six factors emerged, the same division noted in the two separate analyses run earlier. One measure (Stop) was dropped from further consideration at this point. It weighted most on factor 5, together with Figure 8, total cones. However, Stop's contribution was relatively weak (-.50 vs. .89 for the Figure 8), and it was the only significant negative relationship to emerge in the analysis.

The factors themselves, and the tests that define them, are listed in Table 2.
TABLE 1
Results of Factor Analysis. Normalized Loadings of Six Factors on Various Driving Tests.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4  5  6</td>
</tr>
<tr>
<td>Park-Out, Time</td>
<td>.79 .11 -.02 -.02 .04 .09</td>
</tr>
<tr>
<td>Y-Left, Time</td>
<td>.82 -.08 .09 .12 .21 .01</td>
</tr>
<tr>
<td>Y-Right, Time</td>
<td>.83 .06 .30 -.04 -.08 .04</td>
</tr>
<tr>
<td>Small Turn-Right, Time</td>
<td>-.02 .77 .12 -.08 .03 .05</td>
</tr>
<tr>
<td>Small Turn-Left, Time</td>
<td>.09 .97 .02 .15 -.05 .06</td>
</tr>
<tr>
<td>Large Turn-Right, Time</td>
<td>.25 .69 .03 -.01 -.04 .04</td>
</tr>
<tr>
<td>Right Angle-In-Right &amp; Left, Time</td>
<td>.81 .27 .06 .01 .04 -.11</td>
</tr>
<tr>
<td>Right Angle-Out-Right &amp; Left, Time</td>
<td>.88 .13 .20 .04 .07 .18</td>
</tr>
<tr>
<td>Gymkhana-Cones</td>
<td>.11 .10 -.07 .04 .04 .95</td>
</tr>
<tr>
<td>Stop</td>
<td>.06 .40 .27 .19 -.50 .35</td>
</tr>
<tr>
<td>Figure 8-Cones</td>
<td>.19 .02 .14 .09 .89 .09</td>
</tr>
<tr>
<td>Small Turn &amp; Stop-Right-Distance</td>
<td>.22 .15 .86 -.13 .29 -.02</td>
</tr>
<tr>
<td>Large Turn &amp; Stop-Left-Distance</td>
<td>.42 -.01 .70 .16 -.24 -.06</td>
</tr>
<tr>
<td>Right Angle-Left-Distance</td>
<td>.10 .37 .38 .64 .04 -.09</td>
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<tr>
<td>Right Angle-Right-Distance</td>
<td>.04 -.24 -.17 .78 .01 .12</td>
</tr>
</tbody>
</table>
TABLE 2

Listing of Driving Tests Associated With Each Factor.

Factor 1

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Time</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park - Out - Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y - Left - Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y - Right - Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Angle - In - Right</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Angle - Out - Right</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Factor 2

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Turn - Right</td>
<td></td>
</tr>
<tr>
<td>Small Turn - Left</td>
<td></td>
</tr>
<tr>
<td>Large Turn - Right</td>
<td></td>
</tr>
</tbody>
</table>

Factor 3

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Turn and Stop - Right</td>
<td></td>
</tr>
<tr>
<td>Large Turn and Stop - Left</td>
<td></td>
</tr>
</tbody>
</table>

Factor 4

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Angle - Left</td>
<td></td>
</tr>
<tr>
<td>Right Angle - Right</td>
<td></td>
</tr>
</tbody>
</table>

Factor 5

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Cones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 8 - Cones</td>
<td></td>
</tr>
</tbody>
</table>

Factor 6

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Cones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gymkhana - Cones</td>
<td></td>
</tr>
</tbody>
</table>
Factor 1 was loaded by five tests that have in common the speed with which the subjects could execute fairly precise and involved maneuvers at very low speeds.

Factor 2 was loaded by three tests, each of which measured the speed with which the subjects could negotiate a fixed-radius turn in a relatively narrow lane.

Factor 3 was loaded by two tests. These were both multiple-control maneuvers, that required fairly precise use of both steering and braking, although the dependent variable of interest here was the precision with which the vehicle could be stopped.

Factor 4 was also loaded by two tests. These were the same right-angle parking maneuvers that formed part of Factor 1, except the dependent measure in this case was the precision with which the vehicle was positioned relative to the end of the stall.

Factor 5 was loaded by only one test, the Figure 8, using a displaced cone measure. The Figure 8 was an involved turning maneuver, run under time pressure, with only certain points marked by cones. An error in open space after passing one gate (e.g., turning too soon or too late) affected the accuracy with which the subject approached the next gate. It is perhaps mostly a test of the ability to extrapolate the effect of present actions on future course and position.

Factor 6 was also loaded by only one test, the Gymkhana, using a measure of total cones displaced. The Gymkhana involved precise, rapid steering and was run on a fairly well-defined course under time pressure.
DISCUSSION

Comparison With Other Data

As noted earlier, only one other study having aims somewhat similar to those of the present study has been published (Herbert, 1963). However, there are significant differences in the purpose and methods. Herbert was primarily interested in determining whether vehicle operation seemed to tap the same psychomotor factors that had been identified in earlier laboratory tests. Many of his driving tests were structured to evaluate what he viewed as appropriate skills, based on the laboratory data. Other differences in the Herbert study were that the subjects drove trucks, several of the tests were designed for trucks (or at least for vehicles with manual transmissions), and the drivers were all Army personnel. Few of Herbert's 16 tests were similar to those used in this study. Still, it is interesting to compare results.

Herbert reports five factors. These were defined as follows:

1. Multilimb Coordination
2. Spatial Orientation
3. Proprioception
4. Response Orientation
5. Reaction Time

Factor 1, according to Herbert, "involves the ability to coordinate the activity of the extremities...." It is loaded by four measures: hours of driving, time to complete a hill climbing and hill descending course, distance roll-forward while starting on a downgrade, and direction changes while negotiating a very complex maze maneuver. It is worth noting that all but the third test load on other factors in Herbert's analysis with similar or higher weights.
The exclusive relationship of this factor to multilimb coordination is not obvious. None of the tests mentioned are close to tests used in the present battery. However, Factor 3 from the present analysis, which concerned cross-control tasks (stop in a turn), certainly involves multilimb coordination.

Herbert's Factor 2 (spatial orientation) was primarily defined by a parallel parking maneuver, but also included a trailer backing test, and an eyes-closed driving test in addition to the maze test, the hours-of-driving and hill climbing and descending tests described as part of Factor 1. It seems to correspond most closely to Factor 1 from the present investigation.

Factor 3 (proprioception) in Herbert's study was loaded by the eyes-closed test and by distance roll-back while starting on an upgrade, as well as the hill climbing and descending test. The eyes-closed test, in particular, suggests a parallel to Factor 5 in the present study, defined by the Figure 8 test.

Herbert's Factor 4 (response orientation) was loaded by a mirror backing test in addition to the maze and roll-back tests mentioned earlier. These seem to be sampling behavior similar to Factor 4 in the present test.

Finally, Herbert's Factor 5 (reaction time) was loaded by roll-back and roll-forward tests while starting on an upgrade. There does not appear to be a parallel factor in the present study.

Interestingly, although the two studies are different in many significant respects, there appear to be similarities in the results. This would be worth exploring in the future.
Applicability of the Data

The main purpose of the study was to define a minimum battery of driving tests that would adequately cover relevant dimensions of driving performance. Additional criteria which might be considered are to minimize the number of setups and required space.

With the above-mentioned guidelines in mind, the use of the right angle parking tests is logical because, with the same setup and the addition of one measure, it is possible to cover Factors 1 and 4. Similarly, the setup for the small turn allows Factors 2 and 3 to be covered. The large turn loads on the same factors and takes more room, hence it could be dropped.

The Figure 8 test covers Factor 5, is easy to set up, and requires little room. The greatest difficulty may be with Factor 6, which is loaded by the Gymkhana. This test requires a great deal more space than any of the others just mentioned. Because it is spread over a relatively large area and there are a number of "gates," defined by cones, which have to be set up and continuously monitored to derive a score, it is a more difficult test to run as well.

Based on this analysis, it appears that, with the exception of one factor, it is possible to create a comprehensive driving test battery which is compact as well as easy to set up and score.

Limitations of the Data and Suggested Future Research

There are a number of significant limitations to the present study and the extent to which generalizations can be drawn from the data. These are:

1. The tests are all low speed (i.e., 25 mph or less), and involve moderate acceleration forces. Given that this was a
first study, and given the general aims, these seemed like reasonable restrictions. But, additional factors might have been uncovered if tests involving higher speeds and acceleration levels had been included. It would be desirable to explore this possibility in the future. The problem is that such tests require a great deal of space, are somewhat destructive to vehicle components, and pose a greater risk to the subjects. In addition, this is a domain where the dynamic characteristics of the vehicle become quite significant, raising the possibility of different factor structures for different vehicles.

2. While the eventual use of the test battery would involve persons with physical handicaps, the subjects in this study were able-bodied. A different factor structure might have resulted if the test had been conducted using persons with physical handicaps. Three considerations influenced the decision to use able-bodied subjects:

a. It would be very difficult to obtain a sizeable number of subjects with appropriate physical handicaps.

b. It is possible that different types of physical handicaps would yield different factor structures. This would be a major research project in itself, and far beyond the scope of the present effort.

c. The present personal transportation system is designed for able-bodied persons, and, in general, requires the skills that they would typically have. Thus, it does not seem
unreasonable to base this preliminary screening battery on the performance of able-bodied drivers.

3. The relationship of any of the tests used or factors under which they cluster to the likelihood of accidents is unknown. As a practical matter, this relationship probably never will be known exactly. It was not intended that the battery would select "safe" drivers in a definitive and final fashion. Rather the intent was to be able to objectively and economically provide an indication of basic control capability. Such a battery can provide assistance in making a first-step decision whether a particular person or control system or combination of the two is likely to be successful.
REFERENCES
