# Performance Decrement in Twenty-Four Hour Driving

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•THE INCREASING use of multilane interstate highways has caused attention to be focused on the problem of remaining awake behind the wheel. Whether this increased interest is due to an increase in the number of "driver asleep" accidents, or to a decrease in other types of accidents on the freeway, is not known. Whatever the reason for the increased attention, the problem does exist and is likely to become more acute as more people use the freeways for faster and longer trips. As the freeways become more crowded, the single car accidents resulting from drivers falling asleep might be replaced by multi-car accidents resulting from the same cause. This problem is not limited to the superhighway. Performance decrement or decrement in ability to perform can result in just as serious, if not more serious, accidents on our urban and rural roadways.

Results from research in the area of performance decrement in long-term driving might be useful not only in alleviating these driving problems, but also in solving problems existent in areas sharing common factors with the driving task. Some other problem areas might include long-term monitoring of low probability events, the operation of aircraft, or the navigation of ocean vessels or spacecraft for long periods of time. It is evident that the research findings in these latter fields can also be used in the solution of highway problems.

An example of this type of transfer of results is the application of the findings of studies dealing with vigilance effects to highway research. This application is appropriate if we consider that driving on modern freeways and turnpikes is in many respects similar to the low probability event detection tasks employed in many monitoring tasks.

## Operational Definitions of Fatigue

One of the most difficult problems and, yet, a basic problem associated with any study of fatigue is in the definition of fatigue. Typical of the many different definitions that are given for fatigue is the one proposed by Bartlett (1).

> Fatigue is a term used to cover all those determinable changes in the expression of an activity which can be traced to the continuing exercise of that activity under its normal operational conditions, and which can be shown to lead either immediately or after delay, to deterioration in the expression of that activity, or, more simply, to results within the activity that are not wanted.

This definition presupposes that fatigue is undesirable, although there were some authors, most of whom wrote about 30 or 40 years ago on physical fatigue, who described it as a "rather pleasurable sensation," which is not necessarily undesirable. The onset of fatigue, though undesirable, often serves the human operator with a signal warning him of his state of decreased activity, allowing him to stop before complete breakdown occurs.

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## STUDIES OF FATIGUE IN DRIVING

Crawford (2) states that the definition frequently given for fatigue (deterioration in the performance of an activity as a direct result of being engaged in the performance of the activity) is too narrow for describing fatigue in driving. An applicable definition, Crawford feels, should include the possibility of drivers being fatigued from other causes before they start to drive.

Crawford further states that it would appear that there are interrelated aspects of the practical problems of driving and fatigue, namely the fatigue arising from driving, operational fatigue, and the effect of fatigue, from whatever, source, on driving. Crawford then cites several examples of driving research that have been conducted in the past with special emphasis on findings in the areas of fatigue. Jones et al. (5) investigated 889 interstate truck drivers who were stopped after varied lengths of driving and given several psychophysical tests. When these data were compared to data obtained from a control group which had been awake for equal lengths of time, several differences were found. There was a more or less consistent decrease in psychomotor ability with the increasing amount of time on the task. Lauer and Suhr (6) suggest that frequent rest stops while driving are helpful in minimizing the breakdown in performance occurring from driving for extended periods of time. McFarland and Mosely (7) observed bus drivers for 3½-hour periods. They found that steering wheel movements (which occurred about 10 times as often as all other movements) were considerably reduced in the last half hour as compared to the first half hour. Herbert and Jaynes (4) conducted an experiment in which Army and Air Force truck drivers were given tests of driving skill after having actually driven a truck for lengths of time ranging from 0 hours to 9 hours. They found that these skill measures correlated significantly with the hours of fatigue driving. Their results indicated a progressive loss in performance through 7 hours of driving with a slight increase in performance during the ninth hour. The authors of this article explain the increase at the end by suggesting that in the first 7 hours fatigue "builds" unconsciously, but after 8 hours or so, the fatigue is noticeable and the subjects make a conscious effort to combat it and, thus, improve their performance.

Potts (9) and McFarland and Mosely (7) studied near accidents encountered by long haul truck drivers. Twenty drivers were studied over a total distance of 5,000 miles. A total of 48 near accidents were observed during this time. Their findings indicated that the greatest number of near accidents occur within the first couple of hours of driving. It should be noted that Crawford does not mention whether each hour of the distribution was equally represented in the study. Also, no mention is made about what constitutes a near accident. These later results, if they are a valid representation of the actual driving situations on the highway, suggest that an increase in driving time results in a reduction of near accidents and, therefore, a possible reduction in the probability of being involved in an actual accident.

This rather unexpected result is also substantiated by another study reported by McFarland and Mosely (7). These researchers found from insurance records that in 1949, 60 percent of all long haul truck accidents occurred within the first 3½ hours of driving. Again, Crawford does not give the distribution of the number of hours per truck trip so it is not known whether each hour is equally represented in this study.

Crawford also suggests that since many experiments conducted on automobile driving in actual traffic fail to show the effects of fatigue on driving, perhaps these effects should be sought on performance in tasks similar to driving, such as flying for long periods of time.

Drew (3), for example, found in aircraft simulator experiments that performance and accuracy decreased with time, and that instruments outside the immediate range of attention were practically ignored. There was also a tendency for subjects to relax and neglect the task at hand when the end of the experiment was in sight.

Platt (8) states that the following assumptions can be taken to describe the performance of a fatigued driver.

1. Driver fatigue will have an effect on the steering wheel reversal rates, speed change rates, and the average speed of the vehicle.

Figure 1. The instrumented passenger vehicle.

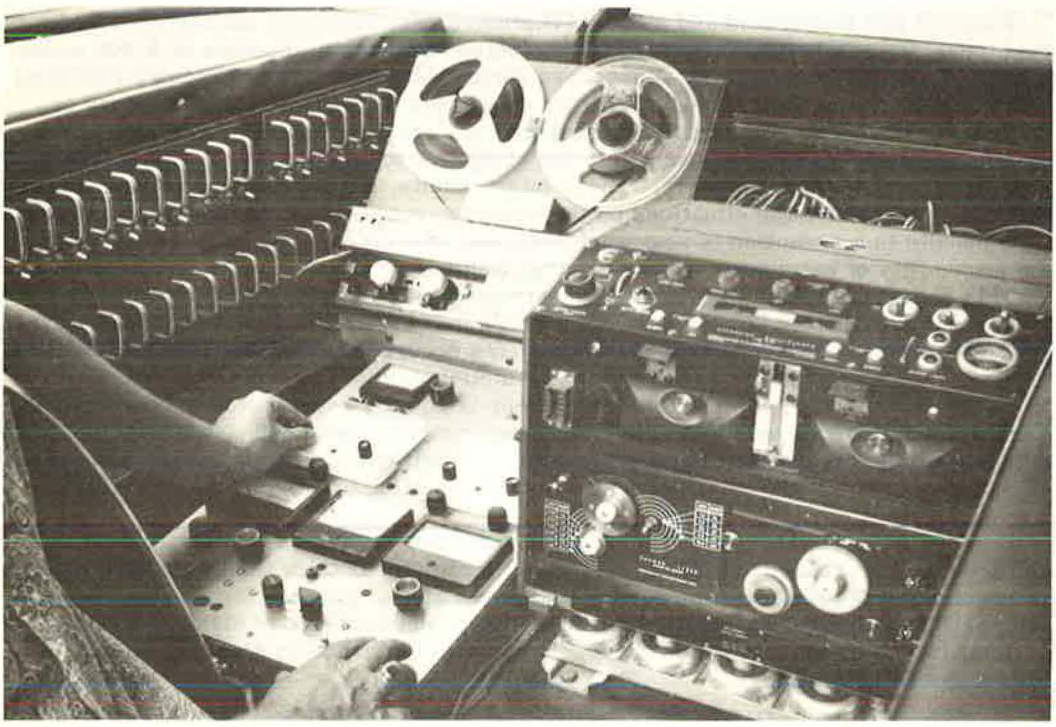

Figure 2. The experimenter's console and the oscillograph recorder.

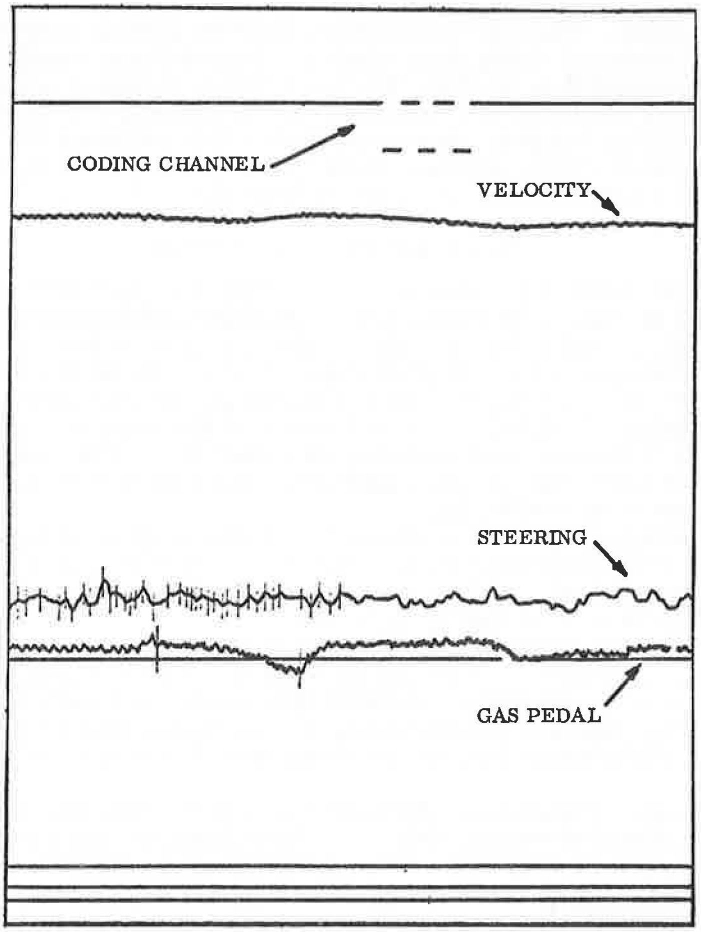


Figure 3. Sample of oscillograph trace.

2. As the driver becomes fatigued, he will accept wider tolerances of both vehicle tracking and speed control.
3. As the driver gets tired, his speed may increase or decrease depending on whether his sensitivity to speed change or steering reversal rate is lost first.
4. The driver will usually take more risks as he becomes more fatigued. This will be indicated by an increase in tracking tolerance, and consequently by a decrease in steering reversals if the vehicle is constant.
5. As the driver becomes tired, his speed change rate increases but he compensates for this by modifying his accelerator reversal rate.
6. The most severe fatigue is encountered when the speed change rate increases and the accelerator reversal rate decreases. This indicates that the driver has ceased to care about controlling his speed.

These assumptions suggest that a study of driving fatigue should utilize recordings of the subject driver's velocity, steering wheel activity, and gas pedal activity.

In all of the research reviewed by the experimenters, none was found where the subject drivers were forced to drive for extremely long times or where they were forced to drive until they broke down. The experiment we conducted was aimed at simulating the situation where a driver attempts to drive "cross country." This type of situation is typified by the serviceman who attempts to drive thousands of miles on a two- or three-day pass to visit his family. This research placed test subjects in "on-the-road" driving situations and measured the performance of the system of which they are a component. This approach does not allow the precise control over variables that might be available in a laboratory situation. Nevertheless, results which are obtained on the highway have the distinct advantage of face validity and of being more readily interpreted into meaningful conclusions. The philosophical problems and stark practical uncertainties which are ever-present when extrapolations are attempted from laboratory simulation results into real-world contexts are minimized, when studies are conducted in a setting in which they are to be interpreted.

## EXPERIMENTAL PROCEDURE

The automobile used in this study was a 1963 Chevrolet sedan (Fig. 1), which had been modified to be used in the experiment. The major modification was the installation of an oscillograph recorder (Fig. 2), which yields a permanent trace of the vehicle and driver performance parameters on photographic paper. The parameters that were recorded include: vehicle velocity, gas pedal position, steering wheel position, and brake pedal position. In addition to these 4 traces, 4 other traces were available for manual encoding of events occurring during the experiment. The events encoded were the beginning and end of data sampling intervals, and encounters of the experimental vehicle with other vehicles (Fig. 3).

Another modification was the installation of a device enabling an experimenter riding in the back seat of the automobile to short out one or two of the spark plugs in the automobile engine, and thus, induce a "miss" into the engine. This was used to test for the effects of fatigue on a "vigilance" type task.

Seven subjects were required to drive for 24-hour periods with rest breaks only at refueling stops. In addition, one subject attempted the experiment under the added condition of prior sleep deprivation and once again under prior sleep deprivation plus the use of the drug, dextroamphetamine sulfate. During the 24-hour period, the subject's vehicular performance was measured continuously with the use of the oscillograph recorder.

Subjects who participated in the experiment were paid volunteers, and all but 2 were students at Ohio State University. One of the other 2 subjects was a male auto mechanic of college age, while the other was a 51-year-old traveling salesman. Each subject was verbally informed, prior to volunteering, about what would be expected of him during the experimentation.

The subjects were told that the amount of money they received would depend on the length of time that they continued driving. They were promised 50 dollars for completing the experiment in its entirety. If they did not finish, they were told they would be paid a lesser amount that would depend on the experimenter's subjective opinion of how hard they had tried to finish.

Seven different subjects, in 9 runs, were tested in this study. The first subject was used solely to test the experimental procedure. Of the remaining 6 subjects, 3 managed to complete the prescribed experimental task in full. One of these did, in fact, volunteer to continue driving beyond the prescribed experiment for extra monetary considerations. A fourth subject was forced to quit because of extremely bad weather. The experimenters made a fifth subject stop, when his performance deteriorated to the point that the experimenters felt that it was unsafe to let him continue. The sixth subject, the 51-year-old salesman, quit $^3/_4$ of the way through the experiment when he felt that it would be detrimental for him to continue.

The typical period of experimentation was conducted in the following manner. The subjects reported to the experimenters at 6:00 a.m. on the day of the experimentation. On arrival they were given a complete vision test including tests for: acuity, phoria, and depth perception. Also a critical flicker fusion rate test was given and the subject's pulse and systolic blood pressure were measured. In addition, they completed the first of the forms designed to obtain the subject's subjective opinion of his own feeling of tiredness. The subject was then shown the experimental vehicle and was instructed to drive it to the intersection that marked the beginning of the test site.

The test site used in this experiment was a section of I71 between Columbus and Cincinnati—chosen because of the lack of geometric and landscape variations. This lack of variation helped to make the task as boring and, hence, as tiring as possible. On arriving at the test site the subject was given the following instructions:

> During the testing period you will be asked to drive this vehicle from here to the outskirts of Cincinnati, a round trip distance of approximately 160 miles, a total of 8 times. Each trip will last about two and one-half hours. At the end of each trip, we will stop for a rest period of about 15 minutes. If at any point during a run you should notice that the automobile engine is behaving erratically, we would like you to report it to the experimenter.

Prior to the start of each journey or run either north or south on the freeway, the subject was given one of the following two sets of instructions:

Normal Velocity Control Instructions

> During this next run I would like you to drive this vehicle in your normal manner at about the speed limit, 70 miles per hour. I would like you to obey the rule that requires you to stay in the right hand lane except when passing other vehicles. I would also request that you refrain from conversing with either experimenter during the run.

or

Constant Velocity Control Instructions

> During this next run I would like you to drive this vehicle at a constant speed of 70 miles per hour (i.e., I want you to hold it as close to 70 miles per hour as you can at all times). I would like you to obey the rule which requires you to stay in the right hand lane except when passing other vehicles. I would also request that you refrain from conversing with either experimenter during the run.

The experimenters also refrained from conversing with the subjects to help make the task even more boring, although the subject had use of the car radio.

The run to which the normal or constant velocity condition was assigned was determined randomly and the design was balanced so that in the 8 trips, 4 of the south runs and 4 of the north runs were "normal" runs, while the other 4 were "constant velocity" runs. This helped to further eliminate any directional biases.

Rest Periods

At the turn around point on the southern side of the test section of highway, the subject stopped only long enough to receive the instructions pertaining to the northern run.

When a trip down and back on the test site was completed, the subject drove the vehicle to a filling station adjacent to the exit of the freeway. Before disembarking from the automobile he was given forms with which to rate his performance and wakefulness and the physiological tests were repeated. After this test was administered, he was allowed to leave the car while it was refueled. The entire break, including testing and refueling, lasted about 15 minutes. At this time the subject was given any food or nonalcoholic beverage he requested.

Use of Drugs

As mentioned previously, the seventh subject repeated the experiment 3 times. In the last 2 repetitions of the experiment the conditions under which the subject performed were slightly different. On the first day that this subject was required to drive, the experimental procedure was the same as that employed on all other subjects.

The procedure employed in the second repetition of the experiment was essentially the same as the procedure employed previously, except that the subject was kept awake a full 24 hours before he started to drive. An experimenter remained with the subject to make certain that he did not sleep. Under these conditions, the subject was able to complete four trips to Cincinnati and back before he felt it necessary to quit (approximately 12 hours).

The subject was also kept awake for a full 24 hours prior to driving in the third trial of the experiment. On this trial, one hour prior to driving and every 4 hours thereafter, the subject was given a 5-mg tablet of dextroamphetamine sulfate. This dosage was prescribed by a physician after a physical examination of the subject. The subject was, in this case, able to complete all 8 prescribed trips to Cincinnati and back. Results of these special tests are described in the next section.

## DATA ANALYSES AND RESULTS

The 4 main performance measures which were obtained from the data collected during the experimentation, velocity means, velocity variances, steering wheel reversals, and gas pedal reversals, were subjected to several regression analyses. The purpose of these analyses was to see if any performance changes appeared to be expressed in these measures as a function of time engaged in task performance.

In the first regression analysis (Table 1), the values of the 4 measures were computed for each trip. A regression line was then found which related the dependent performance measure with time measured in "trips." For this first analysis the values of the performance measures were computed from all data collected during the trip. No distinction was made between data collected during the "constant velocity" portion of the trip and data collected during the "normal" portion of the trip. Table 1 shows quite a difference between subjects, with respect to the correlation of the performance measures with the passage of time. For example, the correlation of gas pedal reversals with time ranges from a value of - 0.818 for subject 2 to a value of 0.921 for subject 7, under conditions of prior sleep depreivation. Similarly, the correlation of velocity mean with driving time ranges from - 0.766 for subject 7 under standard experimental conditions to 0.811 for subject 3. Velocity variance ranged from - 0.947 for subject 7 with prior sleep deprivation to 0.863 for subject 6.

The correlation of steering wheel reversals to the passage of time yielded the most uniform set of correlations. Even so, these correlations range from 0.267 for subject 2 to 0.971 for subject 7 under conditions of prior sleep deprivation and the use of drugs.

These results would seem to indicate that an increase or a decrease in the value of any of these 4 variables cannot be accepted as a universal measure of fatigue. Some of the high correlations suggest that for individual subjects certain of these measures might validly reflect the changed performance state of that driver with the passage of time.

It is interesting to note that the regression lines for subject 7 under conditions of prior sleep deprivation account for a greater amount of variance of the performance measures than do the regression lines for any other subject. This fact might indicate that the 4 performance measures are more valid indicators of fatigue when the fatigue is more extreme than that produced in the normal operating conditions of this experiment, or when activity prior to driving has not been too fatiguing.

Further regression analyses were performed with the data separated by the conditions, constant velocity or normal. The results of these analyses exhibit much the same variation as the first regression analysis. The correlations of velocity variances to the passage of time are, in general, with the exception of the replicate runs on subject 7, higher for the constant velocity condition than for the normal condition. This fact, plus the fact that all correlations are positive, would seem to indicate that the more precise or demanding the experimental task, the more likely decrement in performance, as reflected in the increase of velocity variance, will be related to the passage of time.

### Intra-Trip Variability

When the 4 major performance measures were plotted against time for each of the subjects, a sawtooth type pattern was noted in the graphs, which suggested that perhaps the individual trips and even the periods of time between turn-around points should be examined for evidences of performance decrement trends. Evidence of this intra-trip decrement was found when the periods of time between turn-around points, for normal conditions only, were examined.

TABLE 1

REGRESSION ANALYSIS RESULTS FOR CONDITIONS COMBINED

| Subject | Variable | Correlation[a] | Equation | Std. Error |
|---|---|---|---|---|
| 2 | Vel. $\bar{x}$ | -0.605 | - 0.666x + 72.521 | 0.438 |
| | Vel. $\sigma^2$ | 0.676 | 0.666x + 2.697 | 1.470 |
| | Steer. | 0.267 | 4.228x + 458.533 | 7.619 |
| | Gas | -0.818 | - 29.457x + 415.266 | 10.363 |
| 3 | Vel. $\bar{x}$ | 0.811 | 0.235x + 70.395 | 0.120 |
| | Vel. $\sigma^2$ | 0.689 | 0.234x + 2.150 | 0.173 |
| | Steer. | 0.567 | 25.900x + 403.500 | 26.613 |
| | Gas | -0.510 | - 3.600x + 167.500 | 4.291 |
| 4 | Vel. $\bar{x}$ | -0.040 | - 0.003x + 70.742 | 0.028 |
| | Vel. $\sigma^2$ | 0.608 | 0.248x + 1.748 | 0.122 |
| | Steer. | 0.768 | 23.466x + 520.111 | 7.406 |
| | Gas | 0.739 | 6.950x + 82.694 | 2.393 |
| 5 | Vel. $\bar{x}$ | 0.365 | - 0.176x + 73.052 | 0.224 |
| | Vel. $\sigma^2$ | 0.027 | — | — |
| | Steer. | 0.906 | 32.771x + 548.800 | 7.633 |
| | Gas | 0.729 | 12.771x + 202.133 | 5.990 |
| 6 | Vel. $\bar{x}$ | 0.154 | 0.031x + 71.236 | 0.082 |
| | Vel. $\sigma^2$ | 0.863 | 0.674x + 0.986 | 0.160 |
| | Steer. | 0.838 | 52.904x + 690.928 | 14.056 |
| | Gas | -0.717 | - 9.607x + 204.107 | 3.814 |
| 7 Cond. 1 | Vel. $\bar{x}$ | -0.766 | - 0.258x + 72.117 | 0.088 |
| | Vel. $\sigma^2$ | 0.476 | 0.422x + 4.725 | 0.322 |
| | Steer. | 0.320 | 18.345x + 853.321 | 22.167 |
| | Gas | 0.533 | 2.488x + 111.678 | 1.612 |
| 7 Cond. 2 | Vel. $\bar{x}$ | 0.421 | 0.234x + 75.145 | 0.356 |
| | Vel. $\sigma^2$ | -0.947 | - 0.718x + 10.270 | 0.172 |
| | Steer. | 0.739 | 50.200x + 228.000 | 32.406 |
| | Gas | 0.921 | 4.400x + 228.000 | 1.311 |
| 7 Cond. 3 | Vel. $\bar{x}$ | 0.384 | 0.080x + 73.130 | 0.078 |
| | Vel. $\sigma^2$ | 0.624 | 0.053x + 4.753 | 0.270 |
| | Steer. | 0.971 | 176.130x + 1232.285 | 17.711 |
| | Gas | 0.171 | 1.416x + 230.250 | 3.323 |

[a]Any correlation above ±0.600 is statistically significant.

The values of the 4 major variables were computed for each of these 3 intervals. These values were then ranked. The interval with the highest value of the variable in question was assigned a rank of 3, and the other interval was assigned a rank of 2. This ranking was done separately for each of the 4 variables. The ranks assigned to the first, second, and third intervals were then totaled separately for each variable across all subjects (Fig. 4).

As can be seen from this graph, the lines for velocity, variance, steering reversals, and gas pedal reversals exhibit an increasing trend. This trend, which is significant at the 0.05 level, indicates that within a trip, between turn-arounds, there is a general tendency for velocity variance, steering wheel reversals, and gas pedal reversals to increase. The velocity mean has a tendency to decrease with a trend significant at the 0.05 level within the same period of time.

When these results are viewed at the same time as the results of the regression analysis which yielded some rather high correlations in various directions, it would appear that performance measures might be expected to demonstrate an increase or decrease over time with a sawtooth type variation imposed over the generalized trend (Fig. 5).

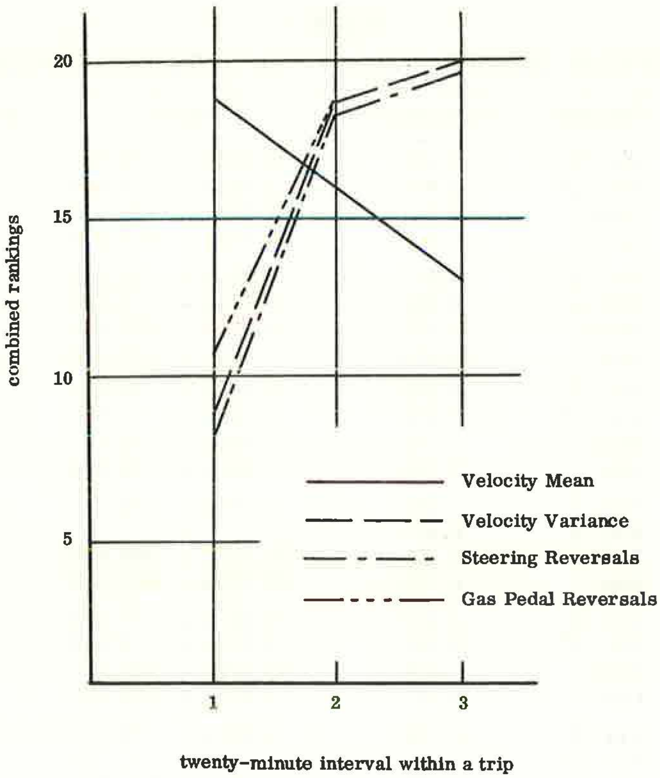


Figure 4. Intra-trip effect.

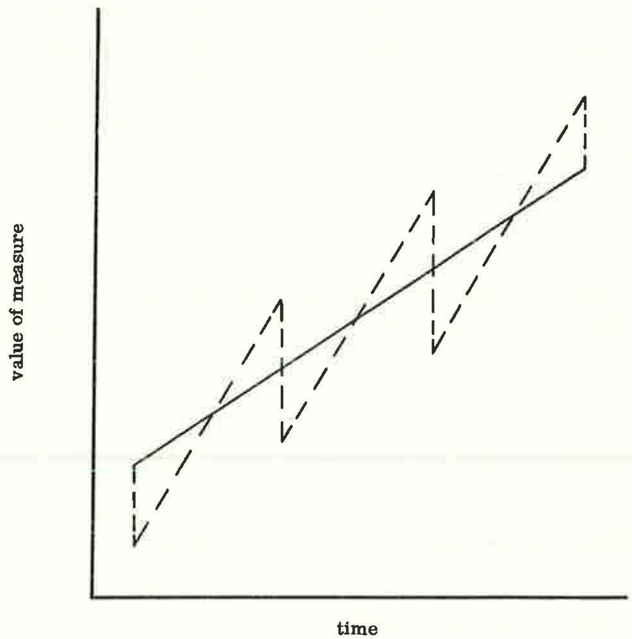


Figure 5. Idealized example of generalized trend with superimposed intra-trip variability.

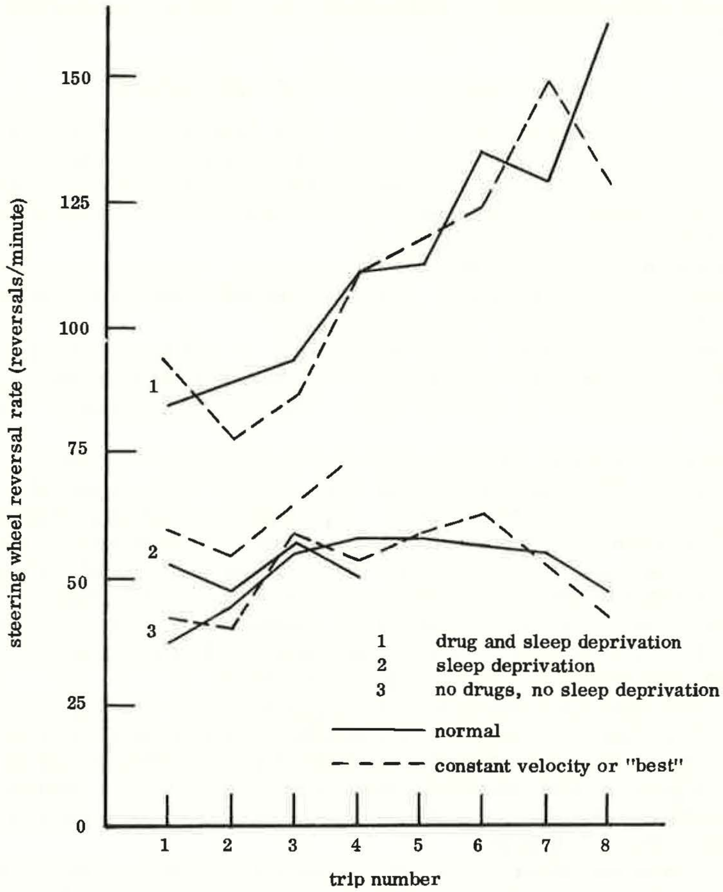


Figure 6. Effect of drug and sleep deprivation on subject driver.

The results of the spark plug miss detection test failed to show any difference with the passage of time. In almost all cases the subjects were able to detect the malfunction. A difference was shown to exist at the 0.10 level of significance for the performance of subject 7 with and without drugs. The drugs noticeably improved his performance on the task.

The forms which the subjects filled out to rate their performance and their state of wakefulness indicated that they felt they were becoming more tired as the experiment progressed. Most subjects continually rated their performance unaffected until the very end of the experiment. This is possibly due to the fact that they might have thought that they would be forced to quit if they gave themselves bad ratings.

The results obtained from the physiological data collected during the experiment were of interest primarily because virtually no change was noticed in any of the measures with the passage of time in the experimental task.

## Effects of Drugs on Steering Wheel Reversals

The most marked effect of the drugs was on the number of steering wheel reversals exhibited by the subject who was tested with and without drugs. Figure 6 shows the steering wheel reversal rate of subject 7 under all three experimental conditions. As can be seen from this graph, the use of drugs resulted in a much larger steering wheel reversal rate than was exhibited in either of the other two cases. In this case the steering wheel reversal rate was more than double that previously exhibited.

The upward trends exhibited by the graphs of steering wheel reversal rate under the use of drugs are both significant, when tested via a T-Test for trend at the 0.01 level of significance.

## DISCUSSION AND INTERPRETATION

One of the most interesting facts to come from this research is that the subject drivers were able to drive as long and as satisfactorily as they did. This is even more surprising when we consider the fact that the subjects engaged in no conversation, received little stimulation from the highway environment, and had virtually no rest except at the brief stops at gasoline stations.

Of the 7 subjects who participated in the research, only 2 were unable to finish the prescribed task of driving 24 hours. These 2 subjects managed to drive for about 21 hours each before they asked or were told to stop.

The fact that most subjects did not break down or fall asleep during the experimental task does not enable the subjects' data to be scrutinized for a pattern in the performance measures, which might be used to foretell a complete breakdown or cessation of performance.

The regression analyses performed on 4 major dependent variables, velocity means, velocity variances, steering wheel reversals, and gas pedal reversals, indicate the degree to which such trends are present. The high correlations obtained for some measures of the dependent variables, with the passage of time for several of the subjects, indicate that such trends do exist. The lack of universality of trends and the fact that the trends for the same variable can be in either direction means that an increase or decrease in the value of one of the dependent variables cannot be taken as an indication of the onset of fatigue, without knowing the specific characteristics of the subject driver that produced the increase or decrease.

The intra-trip effect mentioned earlier suggests that a rest period of a few minutes duration, such as that experienced at the southern turn-around, is nearly as beneficial as the longer gas station rest period experienced at the northern end of the highway. These findings suggest that the policy adopted by some Highway Patrols in the western states of stopping motorists and making them walk around their cars is of some value in reducing the effect of fatigue.

The most prominent effect of the administration of drugs to subject 7 on his third replication, was that he was able to drive twice as long as he had been able to without drugs. In both the drug test and the test previous to the drug test, the subject had been kept awake for 24 hours prior to starting the experiment. On the day the subject took drugs, he claimed that he felt much better than he had on the day when he was not given the drugs. Of interest, also, is the positive effect of drugs on the subject's steering wheel reversals with the passage of time. It is also interesting to note that this subject responded faster to the simulated engine malfunction detection signals when under the influence of drugs than he did under either previous run. This supports the conclusion of researchers who report that drugs maintain high levels of performance in vigilance tasks over extended periods. During the experimentation other phenomena were observed. For example, it was obvious to the experimenters that after several hours of driving, one of the subjects began to exhibit some paranoid-like symptoms.

This subject, as well as other subjects, exhibited a tendency to rely on the edge-stripe on the highway for lateral placement, although on very few occasions did they hit the shoulder. This became obvious when the car passed an exit ramp where the line disappeared and the driver tended to swerve to the right. The tendency appeared to increase with the passage of time, which possibly indicates that the subjects were concentrating on a few visual cues (tunnel vision). This is supported by previous studies (1).

This tunnel vision effect might explain the increase in velocity variance with the passage of time that many subjects exhibited (i.e., tunnel vision resulted in the speedometer being sampled less frequently, and therefore, speed control diminished).

It is possible that the specification of 24 hours of driving served as a goal to the driver. If in future experimentation the length of time that the driver was expected to drive was not specified prior to the start of the experimentation, fatigue effects might be realized earlier in the experiment.

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