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FATIGUE IN DRIVING PERFORMANCE : A LITERATURE SURVEY

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I. INTRODUCTION

The increasing number of highways being built and used as fast and long-distance transport systems has brought to attention the problem of remaining awake behind the wheel. However this is not only a problem of the highways, but also one of the overcrowded urban and rural roads where a decrement in performance at the end of a long trip can also result in serious accidents. Since only a small number of specific experiments on driver fatigue have been carried out in a methodologically rigorous manner, this review will also contain some general findings about fatigue.

The problem of fatigue in driving is twofold. It includes both the fatigue resulting from driving and the effects of fatigue, from whatever source, on driving. Generally it is agreed that performance can be impaired by driving for long periods, but it has been found extremely difficult

1. to define driving performance;
2. to develop adequate techniques of measuring it;
3. to interpret any signs of deterioration in driving performance in terms of fatigue;
4. to define the amount of deterioration which might reduce safety. (Crawford 1961).

The experiments quoted in this review paper should be regarded as attempts to come as close as possible to acceptable driving performance criteria.

II. DEFINITION AND HISTORICAL BACKGROUND

1. The definition of fatigue

Fatigue has at least three meanings:

Subjective fatigue - defined as the feeling of being tired;
physiological fatigue as determined by bodily changes;
objective fatigue - when performance of a task shows a progressive deterioration (Bartley and Chute 1947).

The three phenomena may have little or no relation with each other, e.g. subjective fatigue may not occur in highly emotional situations, even though physiological fatigue may be present.

Fatigue is not always correlated with length and difficulty of a performance. Monotony, aversion to the task, or an emotional stress situation can lead to a strong feeling of being tired, whereas interest and success in a task prevent one from feeling fatigued (Rüssel 1961). Misunderstanding often occurs in discussions because fatigue is used as expression for the state of being tired as well as for the process of becoming tired.

"Fatigue" in this paper will be defined as the state of tiredness after a period of work or performance. The process of becoming tired will be called "stress" (Bartenwerfer 1961). This definition agrees with a classical definition by Muscio (in Poffenberger 1942): "Fatigue is a condition caused by work in which the capacity for work is diminished."

In the use of the term "fatigue" the following seem to be common factors:-

(a) Fatigue occurs after a preceding work or stress.
(b) Fatigue causes a reversible decrement of performance.
(c) Fatigue influences the interaction of psychological functions.
(d) Fatigue decreases the interest in work and increases the feeling of strain.
(e) Fatigue can lead to serious disturbance of personality functions.

2. Short historical background

The first to separate mental from muscular fatigue was Mosso (1884); he noticed also that mental alertness was often correlated with a certain muscular tension. His "ergograph" is still used today for measuring fatigue.

Twelve years later Rivers (1896) using Kraepelin's methods (e.g. a continuous addition task) produced performance curves which consist essentially of three parts:- A rise or improvement, a plateau period and then a drop in performance due to fatigue. This classical performance curve has been confirmed many times in psychological experiments. Wells and Goldmark (1912) pointed out that this decrease in performance may easily be masked by a greater effort being made to maintain its level. Düker (1963) in a series of experiments has demonstrated this compensating effect and explained it as "reaktive

Anspannungssteigerung" (reactive increase in effort). This motivational problem will be discussed in section VIII, p. 21. Bornemann (1953) divides the fatigue process in three sections: in the first phase the specific functions required become fatigued; then, in a second phase, the subject tries to compensate; and, in the third phase, this compensating function also tires. (Bartenwerfer 1961).

M. Smith (1916) demonstrated the lack of a relationship between the subjective feelings of fatigue and the objective work output (in Browne 1953). Thorndike (1924) makes a distinction between two aspects of fatigue: one is the decrement in performance, the other a decrement in readiness to continue.

Bills (1931) showed that transient mental blocks of inactivity increased in frequency with continuous performance until no work could be done at all. Errors in performance tend to increase with the numbers and lengths of the blocks. (Bartenwerfer 1961). A comprehensive review and discussion of research on fatigue and monotony is given by Haider (1962).

This brief summary of different historical approaches should make the complexity of the problem obvious.

III. THE PROBLEM OF "MEASURING" FATIGUE

Driving a car is fatiguing. At least after driving for many hours, especially in heavy traffic, people will say that they feel tired. One might expect a steady decrement in driving performance corresponding to increasing subjective feelings of fatigue. However, it was found that the driver who was tired by long periods of continuous driving, but was concentrating hard at his task cannot be distinguished from a fully rested driver on the basis of driving quality when watched by an observer. (Silver 1963). However, just to watch a person drive cannot be called an objective measure of fatigue, and thus, this finding cannot be regarded as conclusive.

A measure of fatigue should show a continuous change and thus allow prediction of when the breakdown will occur as well as comparison of rates of decrement.

In order to develop objective measures of driver fatigue it is first necessary to agree on a classification of several levels of fatigue which could be described as the following "phases":

a) An increase in nervous tension, resulting in less appropriate responses to normal signals, and irritability.
b) An increasing number of errors because of a loss of the desire to maintain accurate performance.
c) More serious errors resulting from a higher threshold of arousal to danger.
d) Momentary losses of operating control.
e) A complete loss of operating control.
f) A loss of consciousness. (Platt 1963).

This somewhat subjective classification of the levels of fatigue can be objectified by the more specific symptoms that have been found to occur in mental fatigue:

a) Disturbances occur in the receptor system, for example the flicker fusion threshold rises (v. Bracken 1956, Bredenkamp 1956).
b) Perception is influenced, e.g. the red-green after image lasts longer (Haider 1957).
c) Disturbances of co-ordination are found, for example eye-hand co-ordination decreases about 20% (Siddall 1955).
d) Decrease in concentration and alertness is noticed, for instance in multiple choice reaction tests. (Schmidtke 1965).
e) Processes of thinking show alterations, e.g. memorizing can be disturbed (stress research, Schmidtke 1965).

Though these findings do not yet lead to an objective measure of fatigue, but emphasize only single aspects of the problem, measures of these functions may give some indication of fatigue. The question of "what is fatigue" still however remains.

Bartley and Chute discovered three aspects of fatigue (1947):

a) the experience of feeling fatigue, to be measured only by psychological methods
b) the impairment of bodily functions to be measured by physiological or biochemical methods
c) decrement of work output.

So far the most objective approach towards a theory of fatigue is to be found in physiology.

IV. PHYSIOLOGICAL THEORY OF FATIGUE

a) Muscle fatigue results in a decrease in muscular exertion and an increase in time for movement. Fatigue here is a result of higher expenditure of energy than can be compensated for. This causes chemical changes in the muscle. This change of chemical components is a stimulus for the receptors in the muscle and their impulses lead to a nervous reaction in the cortex: the feeling of being tired becomes conscious. Signals are then sent to the muscle to reduce output, that is to stop working.

b) Mental fatigue or fatigue of the central nervous system

From the results of research work it can be deduced that there exists a "centre" of fatigue in the diencephalon region of the brain. From this fatigue centre impulses are sent to the cortex and there lead to the specific suppression of psychomotor functions as known from fatigue research. At the same time impulses are sent also to the autonomic nervous system and cause a trophotrope adjustment there. In this way fatigue leads to a suppression of all cortical functions and thus affects:

Receptor transmission (performance slows down);
attention and alertness;
thinking;
perceptual processes;
psychomotor functions.

Empirical research also showed that the suppression caused by fatigue can be delayed for a short period if "willpower" acts against it. In a physiological theory of fatigue, it can be said that fatigue appears as a result of two antagonistic systems: "fatigue centre" (diencephalon) and "alertness centre" (reticular formation).

It was also found that stimuli to the peripheral nerves excite the cortex through the reticular formation. This is an explanation for the known fact that the suppression of cortical functions and the feeling of tiredness disappear when

a) a fatiguing task is replaced by a new interesting one;
b) the surrounding is changed;
c) fear alarms the organism;

d) the interest in the task is increased by new information;
e) change in the emotional situation takes place.

In summarizing the present neurophysiological knowledge we may consider fatigue as a state of the central nervous system controlled by the antagonistic activity of the inhibitory and activating systems of the brain stem. The regulating systems in turn are susceptible to reaction to stimuli from the surroundings, to stimuli from the conscious part of the brain, and to humoral factors originating within the organism which have the task of regulating sleep, recovery and wakefulness. (Grandjean, 1961, 1968).

Further details of physiological changes associated with fatigue may be found in McFarland (1953) and Tidwell and Sutton (1954).

V. PSYCHOLOGICAL THEORIES ABOUT FATIGUE ("STRESS"-RESEARCH).

Psychological investigations of the problem of fatigue have in common that in all of them stress is assumed to lead to fatigue. Thus for these experiments, the subject is exposed to a stress for as long as the experimenter thinks it necessary to cause fatigue. It is not possible to summarize all the research work that has been done on "stress". Therefore only a limited number of reports essential to our problem will be discussed here.

Since stress cannot be defined in terms of stimulus or response operations alone it is necessary to think of it in terms of an intervening variable. As a starting point for research into the problems of psychological stress and fatigue it is assumed:
a) stress is present before fatigue occurs;
b) the amount of stress increases with duration of performance (Bredenkamp 1966).

Applezweig (1957, in Hoyos 1960) names three causes of failure under stress:
a) the subject fails to react to a stimulus in the adequate way;
b) the subject is unable to react in a satisfactory way due to lack of time, e.g. when a sudden stimulus appears;
c) the subject fails to mobilize the energies necessary for the reaction because of an over-supply of stimuli.

Research into a stress situation has to take into account the motivational structure of the situation as well as with the behaviour pattern of the individual in order to predict a likely failure. In order to obtain valid results of reactions under stress conditions, experiments have been carried out, for example, with neurotics, soldiers in war, people in catastrophes, with induced pain, over-intensified perceptual stimuli, frustration and ordinary working conditions. A general finding in all experiments is that the performance of an individual decreases significantly under stress conditions. In some cases an increased speed with an increase in errors was reported. However, it must be said that no overall stress syndrome in psychology could yet be found.

One must agree that the traffic situation poses various levels of stress, e.g. before starting a trip and when actually behind the steering wheel.

From the point of view of a driver's performance a single trip means acting in a situation in time and space much as is required with performance in a maze. Such a performance consists of continuous orientation and decision making in order to find the way and reach the destination. This performance can be divided into a destination-orientated approach and an environment-orientated approach. The first is determined by small stimulus sections of the latter. Each of these environmental situations is a function of the driver's own movement and consists of a complex and changing stimulus pattern, that has to be responded to by quick and changing reactions. These reactions consist of visual and cognitive performances to analyze and evaluate the traffic situation and of motor performances that guarantee the safe handling of the vehicle.

Stress when driving a car, besides the normal stress of the driving activity, can have different sources:

a) tendencies to reach the destination are obstructed, e.g. by traffic lights, detours, traffic jams etc. - frustration stress;
b) sudden stimulus changes of the surrounding situation - adaptation stress;
c) over-supply of stimuli - perceptual load stress.

We can assume that the driver of a vehicle continually observes stimuli from his environment, which do not always lead to motor responses, such as stepping on the brakes, but nevertheless are visual and cognitive tasks. It can further be assumed that while the driver watches the traffic situation, these stimuli occur in a fairly constant order of velocity and frequency. A stimulus seems to be very sudden when actual and expected stimuli show a discrepancy. For example, if a driver approaches a school, he has to expect that a child may suddenly run into the roadway. The same situation however is a more "sudden" stimulus in a surrounding where it is very unlikely for children to play.

Under certain conditions stimuli can occur at a high rate, for example where there

a) are too many traffic signs;
b) is very heavy and dense traffic;
c) are too many distractions such as advertisements;
d) is a situation such as an accident.

These stimulus patterns in the immediate environment characterized by sudden changes and stimulus over-supply could be called psychophysical stress. It can be assumed that the ability to cope with this stress differs between individuals, possibly also within individuals at different times.

As research with projective techniques has not contributed a predictive method of individual stress tolerance, attempts have been made to assess stress tolerance by means of multiple choice reaction time devices. A decrement of the ability to cope with stress induced by a multiple choice reaction device ("Kieler Determinations-gerät") has been demonstrated (Hoyos 1960).

Besides the multiple reaction devices in experiments on stress and fatigue, another approach has been the measurement of the "critical flicker fusion frequency" (CFF). The CFF is the number of successive light stimuli per second that are just not perceived as separate, but as continuous light (a threshold measure). The fusion occurs because the positive after image of the first light pulse is perceived together with the following light pulse.

In experimental conditions a stress is created for example by performance in arithmetic problems and the CFF is measured for different time intervals. Results indicate that the flicker fusion frequency decreases with duration of the mental task. If pauses are induced by measuring the threshold more frequently (e.g. every ten minutes) the CFF rises first and reaches a plateau and then decreases. It could be that after a small pause more effort is necessary to continue. This additional strain could become an activator for a certain time to keep the level of fatigue constant (v. Bracken 1956; Schmidtke 1951; Bredenkamp 1966).

It is possible to deduct from these theories and findings some essential applications for the problem of driver fatigue (Vi, below), but first more specific experiments about driving performance shall be reported.

VI. Research into the SPECIFIC PROBLEM OF DRIVER FATIGUE

Human factor studies often involve the use of simulation. Simulation permits the economical and easy manipulation of what seems to be the primary variable in a given experimental situation.

1. Experiments under simulated driving conditions

a) Concentration maintenance:

An experiment carried out in Japan considered the functions of concentration maintenance as a basic problem for driving and fatigue. Therefore an apparatus was constructed where the examinee aims at a target at a distance of two meters with a gun-barrel with a sighting telescope. Aiming is kept up for periods of one minute and the state of concentration in keeping up target-aiming is described as a continuous curve. In this manner weekly curves for 13 subjects of each sex were obtained.

The curves were taken before and after examinations of the students and showed an overall decrease after the examination. It is deducted from this experiment that it would be valuable to use this approach in road research (Takakuwa 1962).

b) Tracking task:

It can be assumed that a tracking task demands continuous attention similar to the performance when driving a car and that mental blocks or gaps in the perceptual response would occur, when fatiguing is involved. This should cause tracking to become momentarily uncontrolled. In an experiment by Siddall et al. (1955), 21 subjects were tested for uninterrupted periods of two hours. They were required to keep a target correctly aligned by cranking a handwheel at a certain speed; it was expected that failures to attend to the display would result in target deviations.

Analysis of the results showed that both the number of errors and mean duration of errors increased significantly in consecutive half hour periods. It was also found that large individual differences in performance occurred (Siddall et al. 1955).

c) Vigilance and target detection:

Vigilance or monitoring behaviour is required when an operator must detect aperiodic stimulus changes in his environment; whereas target detection involves the location and recognition of specific aspects of a stimulus situation confronting the operator. One can say that vigilance and target detection performance are integral parts of operator performance. Therefore this performance will be most seriously affected by prolonged mental operations, which result in mental fatigue, and somewhat less affected by motor fatigue. This hypothesis was tested with 80 male subjects, 40 performing a vigilance task and 40 a target detection task. The subjects in each of these groups were assigned to one of four sub-groups, three fatigue groups and a control group. The three fatigue conditions chosen were:-

(i) Mental fatigue condition: Subjects in this group were required to work multiplication problems mentally for four hours before being tested. Four and five digit numbers had to be multiplied mentally by a one digit number.

(ii) Driving condition A: Subjects were required to operate a driving device for a four hour period (Drivometer);

(iii) Driving condition B: The subjects also operated a driving device for four hours but were in addition required to monitor a pair of red lights that periodically increased in intensity.

Vigilance Apparatus: After one of the fatigue conditions the subject was seated in a sound-treated room facing a circular 18" (46 cm.) ground glass screen. The screen was in front of the subject at a distance of 36" (91.4 cm). Whenever the subject detected a faint flash of light that appeared on the screen, he was to flick a toggle switch. The light was a faint, near-threshold, circular spot 6 mm in diameter, with ill-defined edges. Data were recorded for each subject over five 20 min. trials. During each of these 20 minute trials a subject was presented with 20 signals. A subject's score for a trial was the number of signals missed. A reward system was used which would tend to maintain a relatively high level of motivation and consequently reduce errors in the task. A subject was paid 5 cents for each signal detected but fined 10 cents for missing and false responses.

Target detection apparatus: The subject was required to detect an odd or different letter from a background of similar letters. The odd letter was considered as the critical target to be detected, whereas the other letters which were identical to one another, served as background figures. The letters were shown on slides projected on a screen. In 192 slides there were 96 with a critical target. The scoring and rewarding system was the same as above.

The results can be summarized as follows:

Subjects exposed to the mental fatigue condition prior to testing in the vigilance task missed significantly more signals than subjects in the control group and in driving condition A. The control group performed better in the vigilance task. In the mental fatigue group, the fatigue effects were most apparent. Similarly, the target detection task showed significantly fewer errors in the control than in all the fatigue conditions.

The basic hypothesis therefore seems to be acceptable, that both vigilance and target detection seem to be susceptible to the influence of fatigue, with an increasing number of errors in mental fatigue tasks (Heimstra 1964, Heimstra et al. 1964).

d) Driving in a car simulator:

In Sweden the effects of four hours continuous driving in a car simulator on the performance in simulated driving were observed. The results indicated that all subjects had a successive performance decrement over time together with an increased feeling of fatigue. Pulse rate, respiratory rate and skin conductance level also showed continuous decrement over time (Dureman and Boden 1968).

2. Experiments involving vehicle driving

a) Measuring of "spare mental capacity"

One of the difficulties which faces us in studies of the car driver is the impossibility of determining a driver's level of concentration by recording his overt behaviour. Speaking in the language of information theory, we can assume that a driver has a greater capacity for dealing with information than is usually required in driving. We could call this the "spare capacity" which he draws on in an emergency and with which he compensates for the increased difficulty of his task e.g. when fatigued. When performing a primary task where a consistent level of performance must be maintained, errors must occur on a subsidiary task when both demands together exceed individual capacity. If the demands of the subsidiary task remains constant, then errors in it must reflect fluctuations in the demands of the primary task, for example driving. To test this hypothesis, auditory subsidiary tasks were applied in two different levels of traffic: increased traffic should require the subject to deal with more information and therefore lead to decreased "spare capacity". As a result of this decrease, more errors should occur in the subsidiary task when the difficulty level of the primary task (e.g. driving) is raised.

For this experiment an auditory task - detecting changes in successive eight digit numbers - was used and the increase in error rate due to heavier traffic proved to be significant at the 5% level.

These findings were then taken as a hypothesis to test the influence of fatigue on driving. Policemen on "mobile patrol" were chosen for this experiment, as they do actually drive during their working hours. One shift worked from 8 a.m. to 4 p.m., the other shift from 4 p.m. to midnight. The suitable testing time therefore was shortly before or shortly after 4 p.m., to have the two conditions "before" and "after" driving. The test route of three km was always the same. Fatigue which resulted from previous driving might be expected to reduce "spare capacity" (as defined) and therefore more errors should be found on the auditory task in the "after driving" condition.

One of the tasks required the subject to listen to a continuous series of random digits, one of which was pronounced every 1¼ sec. He had to pick out three successive digits which occurred in the order odd-even-odd. When he detected a group he responded verbally.

The other task required the subject to listen to a series of ten letters, read so that a series was started every five seconds. Eight letters in the series were different from one another and one letter occurred twice. At the end of the series the subject had to tell which one had occurred twice. One of the series was given every minute. Both tasks were presented by a tape recorder. The rather unexpected result occurred that spare capacity was greater on the average after 8 hours on mobile patrol, than before. An explanation for this could be that all subjects got up nearly at the same time - regardless of the beginning of the patrol shift. The time to 4 p.m. was filled with garden work and other odd jobs, so that fatigue which accumulated during these jobs apparently transferred to the test with greater effect that that produced by previous driving.

A second possibility is that the men working from 4 p.m. to midnight were suffering from the cumulative effects of too little sleep, since they may have had only 6 hours sleep for several previous nights.

A third possibility is that the result is due to an "end effect" with the subjects who worked from 8 a.m. to 4 p.m., as they were tested just before going off duty and might have been more co-operative than men who were just preparing to work until midnight (Brown, 1962).

To answer the problems clearly better designed experiments using this method would be of value.

b) Measuring driver's performance with the Greenshields Drivometer

A device was designed - the drivometer - to record the actions of the driver and the response motions of the vehicle. The counts recorded include the following:-

steering wheel reversals of more than 3/8" (9.5 mm);
acceleration reversals: a measurement of the accelerator approximately 1/8" (3.2 mm) up or down makes a half count; thus, there is a count for each accelerator reversal;
brake applications: a count for each brake application;
speed change: one half count for every two miles per hour (3.2 km/h) increase or decrease in vehicle speed; thus, the amount of speed change in miles per hour for any time interval may be found by multiplying the dial count by four.

The device was tried out with 7 students on an expressway, where the physical features of the road would be practically constant.

However, except for the frequency of the steering wheel reversals, no consistent alteration in performance for all subjects was found with duration of driving. As the drivometer however seems to be an adequate device for measuring driver's reactions a further study with a large number and variety of drivers is suggested (Greenshields, 1966).

Another experiment by Safford (1965) with a similar device installed in a car required seven subjects to drive for 24 hours, however no valid conclusions could be obtained due to the small number of subjects and great individual differences.

c) Measuring performance by actual driving tasks (truck driving)

In order to measure actual driving performance under the influence of fatigue, several measures of skills for driving a truck were designed. In the driving tests the subject was told to drive rapidly but accurately.

Driving measures used:

1. Precision steering. A straight path 6½ ft. x 200 ft. (1.98m x 61 m). Driving once forward, then once in reverse without contacting the boundary lines. Score: total time, number of errors, distance-in-error.

2. Figure "8". An 8-shaped path 7 ft. (2.13m) in width, with one of the circles 30 ft. (9.15m) in diameter and the other 50 ft. (15.25m) in diameter. Score: total time and number of errors.

3. Flag. Ten flag staffs in a line, with a distance of 30 ft. (9.15m) between adjacent flags. The driver was required to drive forward, passing alternately to the right, then to the left of each successive flag. This was then repeated in reverse. Score: total time.

4. No-slip-back. A path 10 ft. x 40 ft. (3.05m x 12.20m) was situated at a 15° incline. The driver had to drive forward, half the distance up the slope, then come to a stop and then proceed to the top without any backward slip. No hand brake was allowed to be used. Score: distance-in-error.

5. No-slip-forward. This was the same procedure as above, except that the vehicle was headed down the slope, and was to be reversed to the top of the hill.

6. Mirror reverse. A straight path 6½ ft. x 167 ft. (1.98m x 50.90m) was outlined by tape. The truck was positioned between the boundary lines at one end of the path, the windshield was covered and the subject instructed to back to the other end of the path using the side mirror for guidance. He was told that the four truck wheels could touch the lines but could not go beyond their limits. Score: distance-in-error.

7. Non-visual. A straight, crushed rock path 12" x 167 ft. (0.30m x 50.90m) was set flush into the desert hard-pan. The two left wheels of the truck were positioned on the rock path at one end, the driver wore blackout goggles, and was instructed to drive forward to the far end without leaving the rock path. Score: distance-in-error.

8. Parallel-park left. A 3 ft. x 7½ ft. x 23 ft. (0.91m x 2.29m x 7.01m) stall was located to the left of the driver. The driver was instructed to pull forward, come to a stop at an appropriate place, and then back into the stall. Score: total time, direction changes, number of errors.

9. Parallel-park right. The same as above, only the stall was located to the right of the driver.

10. Trailer-back. The subject backed a 500 gallon (2275 l) water trailer into a stall 8 ft. x 15 ft. (2.44m x 4.57m). The task was

complicated by positioning the truck and trailer 30 ft. (9.15m) in front and 30 ft. (9.15m) to the left and at a 90° angle to the stall opening. Maneuvering was further restricted to a 60 ft. (18.29m) square space immediately in front of the stall. Score: total time, direction changes, number of errors.

11. Maze. This consisted of two 25 ft. (7.62m) square "jockeying" boxes connected at diagonal corners by an alley 8 ft. (2.44m) wide and 20 ft. (6.10m) in length. Alleys of the same dimensions placed at right angles to the connecting alley served as entrances to the boxes. The subject was instructed to back through the entire maze. Forward motion was restricted to activity in the boxes. Score: total time, direction changes, errors.

12. Contour. A specially contoured trough 180 ft. (54.86m) long and 32 ft. (9.75m) wide was constructed. In cross-section the middle portion was 3 ft. (0.91m) below ground level. The lateral portions sloped upward to ground level. Three circular, interlocking paths were positioned diagonally upon the trough. The path width was 7 ft. (2.13m) except at the point of contact between adjacent circles, where it expanded to 10 ft. (3.05m). The diameter of each circle to the centre point of the path was 27½ ft. (8.38m). After the driver's door window had been blacked-out, he was told to drive through the interlocking circules in a clockwise direction and come to a stop at his starting point. He was to keep both front wheels from touching the boundary lines of the path. Score: total time, time in error, number of errors (see drawing Herbert 1963).

180 subjects drove a truck on a fatigue course after an initial test and prior to a retest on the battery. Five groups of subjects were selected, according to the number of hours they were requested to drive: 0, 1, 3, 7, 9, hours duration were chosen. Pre- and post-fatigue test results were correlated with hours of fatigue driving. The data obtained show a variable loss in function on each of the measures taken, however not a continually increasing loss in skill as driving task length increases. The 9-hour group showed an improvement over the 7-hour group. One explanation for a possible recovery may be that a gradual but unconscious build up of fatigue occurs over several hours of driving. Once the condition becomes obvious to the subject, (at about 8 hours)

a conscious effort is made to compensate and thus effect a return to a higher skill level (Herbert 1963).

d) Sleep deprivation effects:

14 sleep-deprived subjects were given experimental runs on the highway in a dual control car. The drivers were instructed to drive safely at the speed limit, to report intentional changes of speed and reasons for them, and to report any potential hazards ahead but otherwise to drive normally. At half hour intervals the driver was asked to report his subjective feelings of alertness or fatigue. Each subject was given a five-hour run after normal sleep and after sleep deprivation. In a first experiment "concentrated" sleep deprivation from 24 to 36 hours was used, in a second experiment the subjects were allowed not to sleep more than 4 hours in three consecutive nights.

A tester recorded the driver's behaviour on a checklist for all runs. Included were, for example, unintentional speed changes, eye blinks and closures, restless body movements and others. For gathering these data a time-sampling procedure (5 minute period) was used.

Statistically significant differences between normal and "deprived" runs were found with differences in number of drifts, number of unnecessary speed decreases, and mean number of eye closures and eye blinks. It was also reported that 4 drivers dozed at the wheel within less than three hours of driving in spite of the awakening effect of reporting tasks and questioning by the observer (Forbes et al. 1958).

VII. INFLUENCE OF REST PAUSES

Rest pauses have been effectively utilized in certain industries to combat the loss in worker efficiency due to fatigue and monotony. Although there is no complete agreement as to the optimum length of time for the pause or when it should be introduced in the work period, its value is generally recognized.

To study the effect of rest pauses on driving, a controlled experimental approach using matched groups to determine their performance in a simulated driving situation, continuing for a 3-hour period was used. The groups were matched as nearly as possible in respect of sex, age, and driving experience. The no-pause group - 28 subjects - drove for three hours straight, receiving no pause or refreshment. The other 25 subjects - the experimental group - were served tea before driving. After $1\frac{1}{2}$ hours of continuous driving each was given a 15-minute rest period, and again tea was served.

A series of efficiency tests was administered, before and after the simulated driving, in the following order:

1. Blood pressure.

2. Steadiness test. A stylus $^1/8''$ (3.2mm) in diameter is moved down between two brass strips which are $^3/8''$ (9.5 mm) apart at the bottom. When either plate is touched a light flashes and the trial ends. The score is read from a calibrated scale on one of the plates. A series of ten trials, alternating hands each trial, constitutes the test.

3. Serial choice reaction time. The subject is seated with the right foot placed on a brake type switch adjacent to a simulated brake pedal and is instructed to hold the right foot on the switch just as though pressing the accelerator of an automobile. Green, amber and red stimulus lights are presented in random order. The subject is instructed to respond only to the red light; that is as soon as the red light appears he is to move the right foot from the switch and place it on the brake pedal as quickly as possible.

The apparatus records only the reaction time to the red light. False or wrong reactions, such as responding to the green light, are merely counted. The test continues until the red light is presented 25 times.

4. Gross co-ordination. This is measured by the following device: A tilting table maze is controlled by means of two levers. One lever tilts the table top upward or downward from front to back, the other tilts it in a similar manner from left to right. A steel ball can be guided around the lanes of the maze by manipulating the levers. At various places along the course are located 1-in. holes through which the ball will drop if the levers are not manipulated properly to maneuvre it around them. The object is to guide the ball through the maze without its falling into any of the holes. When the ball falls through a trial is completed. The holes are numbered progressively so that the farther the ball advances around the maze before it falls

through a hole, the higher the score. (The number of the hole determines the score value for the trial). In this experiment each subject was given five trials and the mean of the scores was recorded.

5. Grip endurance. The subject was asked to take the dynamometer in the preferred hand and grip it as hard as possible for 1 minute. The percentage of loss from the original level attained was taken as the score.

6. Card sorting. The equipment consisted of a deck of Rook cards and four small boxes with one of the following colours printed on the front of each: yellow, red, green or black. The cards were shuffled and handed, face down, to the subjects with the instructions to turn the deck over, look at the top card, state aloud the colour, then place it in the proper box. The subject was given only one chance for each card. Thus if a card was placed in a wrong box it remained there. The object was to see how rapidly the cards could be sorted. The number of errors was also recorded.

7. Mental addition. Twenty addition problems, each composed of five two-digit numbers, constituted the test. One minute was allowed for computation. The number of problems attempted and number of errors was recorded.

8. Efficiency in observing or attention to detail. This is a paper and pencil test consisting of several rows of the same letter. From one to four other letters of near-identical design were inserted in some of the rows. Two minutes were allowed for counting the number of odd letters in the several rows. Rows attempted and errors were recorded.

9. Galvanic skin response, pulse and respiration. A graphic record was obtained for a period of 1 minute for each measurement before and after driving.

For driving performance a "drivometer" was used. The drivometer used here is a device so constructed that the subjects sits in a mock-up car using full size automobile controls to drive a miniature car around a travelling road-way. In order to obtain a steering score, vertical protrusions are attached to the right side of the roadway in such a fashion that when the miniature car passes one, it operates a quick-acting counter. The total number of contacts made constitute the steering score.

A signal box containing a red and green light similar to the conventional traffic control devices is placed above and to the right of the travelling roadway. The time required for the subject to depress the brake pedal after a red light appears in the signal box is described as stop-light-response time.

An electric train emerges from a tunnel into the view of the driver at the will of the experimenter. The driver is instructed to press the brake pedal as soon as he sees the train (train-reaction time).

Above the roadway there is a small aperture through which printed instructions are presented. To the right of the driver is a control box on which the same instructions appear. The subject is required to stop the car as soon as he sees instructions appear and plug in a jack below the matching instructions on the control box. The time required to perform this is the error time. Before the actual experiment started, a test-run was made (Lauer and Suhr 1957).

As the number of subjects in this experiment was too small to draw any valid conclusions, the same tests and the same "driving" procedure were used in a second experiment.

Two experimental procedures were applied:

Experiment A: the control group was required to drive 3 hours without pause; the experimental group had a teabreak of 15 minutes after $1\frac{1}{2}$ hours of driving.

Experiment B: The control group was required to drive six hours, with a 15 minute pause every $\frac{1}{2}$ hour of driving.

56 subjects took part in the experiments. From the analyzed results the following conclusions could be drawn:

1. The onset of work decrement occurs within the first two hours of the simulated automobile driving task.

2. A refreshment pause substantially prolongs the onset of fatigue and reduces the extent of work decrement resulting from a prolonged period of simulated automobile driving.

3. Drivers either cannot or do not accurately evaluate subjectively their own level of driving performance efficiency.

4. A refreshment pause will increase maximum efficiency of performance.

5. Drivers become less efficient after two hours of continuous driving (Suhr 1959).

VIII. THE INFLUENCE OF MOTIVATION

All experimental findings of research into the problem of fatigue showed clearly an inter-individual difference of susceptibility to fatigue as a whole and also a difference in the degree of impairment of single functions (Voigt 1957).

There is some evidence that, depending on the situation, a larger or smaller proportion of such individual differences can be attributed to differences in volitional functions or "motivation". Experimental studies in this field are scarce and would have to cope with all the additional difficulties encountered in research on motivation, which in itself is a highly complex, multi-dimensional aspect of behaviour.

A study with Navy personnel clearly shows the effects of what is called "motivation" - the variable that is supposed to cause the differences: Navy personnel were tested for sixty hour periods. It was found that in one of the tasks performance decreased considerably with the progression of time, whereas the performance in a battle game that was enjoyed by the subjects showed a high performance throughout (Wilkinson in Safford 1967). So far, no conclusive research results about motivation in driving and its influence on fatigue are available. They would have to take into account at least the following sources of variation:-

1. individual differences from subject to subject
2. variation in the same person on different days or under altered circumstances
3. different incentives or levels of motivation (Schwab 1953), including the degree of challenge and satisfaction experienced in the driving job.

Generally speaking for a job to be satisfying three conditions seem to be necessary and sufficient:

a) they must demand of the operator the utilization of skills
b) they must be meaningful
c) the operator must have real responsibility (Jordan 1962).

Driving is usually a challenging experience and should as a task be motivating for the individual. As motivation was found in general to exert an influence on the degree of fatigue (see historic background), it would be a valuable task to construct experimental conditions for the assessment of the influence of motivation on driver's fatigue.

IX. CONCLUSIONS

1. The study of fatigue in drivers is hindered by the fact that no clear definition of driving performance and no reliable method of measuring it has been found.

2. When planning an experiment on fatigue, three aspects should be distinguished and included or separately examined: subjective fatigue physiological fatigue, objective fatigue.

3. "Fatigue" (as opposed to "stress") should be defined as the "state of tiredness" after a period of work or performance.

4. For future research the neurophysiological knowledge of fatigue should also be considered:
As the body's regulating systems are sensitive to stimuli from both the environment and the conscious part of the brain, an experiment has to be well planned to keep these variables (e.g. fatigue reducing stimulations) constant for all subjects.

5. Research into a "stress"-situation has to cope with the motivational structure of the situation as well as with the behaviour pattern of the individual in order to predict the likelihood of stress-induced failure.

6. Three types of stress situations - frustration stress, adaptation stress and perceptual load stress - should be distinguished and/or included in further experiments.

7. The most valuable approach towards measuring driver's fatigue is to be found in experiments involving actual driving situations. It is suggested for further research to combine the concept of "spare mental capacity" with especially designed car driving tasks.

8. It can be said that the onset of fatigue is substantially prolonged when a rest and/or refreshment pause is introduced. An experiment with pauses, with or without a stimulant such as tea, should be included in further research work.

9. The compensating effects of motivation or "will power" are not yet well known. However since experiments with mental tasks show the influence of these factors (Düker 1963), their relevance should be tested in car driving experiments.

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