Effects of Fatigue on Basic Processes Involved in Human Operator Performance

I. Simple Vigilance and Target Detection

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•THE PURPOSE of the present investigation was to determine the effects of exposure to several fatigue-inducing situations on performance on two perceptual tasks—vigilance and target detection. Both of these tasks are of importance in most settings where a human operator is involved. Vigilance, or monitoring behavior, 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.

A considerable amount of research has been conducted in these areas during the past few years with particular emphasis on vigilance behavior. In these investigations a number of task and environmental variables have been studied. For example, studies have been concerned with the effects of such variables as rate of signal presentation, intersignal interval, signal magnitude, background noise, etc., on vigilance performance. In addition to task and environmental variables, the so-called subject variables have also received some attention by researchers. This class of variables would include motivational, personality, perceptual, or experimental factors.

Fatigue could be considered as a variable that would most appropriately be classified as a subject variable. Although considerable research has been conducted dealing with effects of fatigue on operator performance, results are frequently contradictory. In general, most findings suggest that fatigue has little or no effect on most performance measures (4). However, inasmuch as vigilance is a rather basic process that is sensitive to a number of variables, it may also be sensitive to fatigue. This is also true of target detection. Consequently, the investigation reported here was conducted to determine if these measures were sensitive to fatigue.

METHODS

Subjects

Eighty male subjects were used; 40 in the vigilance phase of the investigation and 40 in the target detection phase. Subjects in each of the phases were assigned to one of four groups—three fatigue groups and a control group. This resulted in a total of 10 subjects in each of the four groups in the vigilance and target detection phase. The subjects were all college students and were paid to participate in the investigation.

Apparatus and Procedures

Subjects that had previously been exposed to one of three fatigue conditions, as well as non-fatigued control subjects, were tested in either a vigilance task or a target detection task. The three fatigue conditions are described, as follows:

1. Mental Fatigue Condition. Subjects in this condition were required to work multiplication problems mentally for 4 hr before being tested in the vigilance or target

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detection task. The subjects were presented with a booklet containing the problems and were instructed to perform the multiplication "in their head" and to place their answer beside the problem in the booklet. The problems consisted of four- or five-digit numbers that were to be multiplied by a one-digit number. The subjects were under the impression that the booklets would be corrected and were urged to do their best. In general, the technique was somewhat similar to that used in other investigations concerned with mental fatigue (1, 3).

2. Driving Condition A. Subjects were required to operate a driving device for a 4-hr period. The task consisted of maintaining a model automobile on a moving belt by means of a standard automobile steering wheel. When the car was not properly maintained on the belt an electrical contact was broken and a timer activated. This permitted a measure of "time off the road" for each subject. Although this measure was not used in the present investigation, the subjects were under the impression that this was a critical measure and were urged to do their best.

3. Driving Condition B. Subjects also operated the device for a 4-hr period. In addition, they were required to monitor a pair of red lights that periodically increased in intensity. These lights were located approximately 7 ft in front of the operator at the end of the belt in the driving device.

In many respects the driving device was similar to that used by Suhr (6) in his studies concerned with the effects of a periodic refreshment pause on simulated-automobile driving performance.

The 4-hr period that the subjects were exposed to the driving conditions was selected on the basis of subjective reports by subjects that had operated the device in preliminary research. Although longer periods of time could have been used, it was felt that the sensitivity of vigilance and target detection performance to fatigue could best be evaluated when fatigue was minimal.

Vigilance Apparatus.—The subject, immediately after completion of a fatigue condition, was seated in a sound-treated room facing a circular 18-in. ground glass screen. The screen was located approximately 36 in. in front of the subject. Whenever a subject detected a faint flash of light that appeared on the screen, he was to flick a toggle switch. The light, or signal, 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-min trials a subject was presented with 20 signals. A subject's score for a trial was the number of signals missed. Intersignal intervals ranged from a minimum of 4 sec to a maximum of 250 sec.

When seated in the vigilance test room, a subject was initially presented with 10 signals in a 1-min period. This was to insure that the subject knew where the signal was located and was familiar with the response required. Following the last signal presented in the vigilance session, the 10 signals were again repeated.

Because the primary purpose of the investigation was to determine fatigue effects, the total number of signals missed was a more meaningful measure than pattern of errors or vigilance decrement. Thus a reward system was used which would tend to maintain a relatively high level of motivation and consequently reduce errors in the vigilance task. A subject was paid $0.05 for each signal detected but was fined $0.10 for each missed signal and false response. A reward system of this nature has been shown to maintain vigilance performance at a higher level (5). Also, the short mean intersignal interval used would tend to reduce errors.

Target Detection Apparatus.—The target detection task involved the detection of 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 with each other, served as background figures. Three background conditions were used with 8, 16, and 32 letters. In each case the background letters were similar in shape to the critical target. Letter combinations were B-R, E-F, C-O, and X-Y.

Each configuration was presented to the subject by means of a slide that was projected on a screen. A total of 192 slides were used and consisted of 96 slides which actually contained a critical target and 96 "dummy" slides that contained only back-

ground figures. An equal number of 8, 16, and 32 figure configurations were presented in randomized order. The entire series of 192 slides was repeated so that a subject was exposed to a total of 384 configurations during a test session. Each of the configurations was exposed for a 2-sec interval and there was a 2-sec interval between presentations.

The subject's task was to determine if the configuration contained a letter that was different from the background letter or if it contained no different letter or critical target. The subject recorded his decision in a booklet.

RESULTS AND DISCUSSION

Subjects with previous exposure to the fatigue conditions tended to miss more signals in the vigilance task than the control subjects. Differences in the number of signals missed by subjects in the various conditions were tested for significance by means of the Mann-Whitney U-test. It was found that subjects exposed to the mental fatigue condition prior to testing in the vigilance task missed significantly more signals than subjects in the control group ($p < 0.025$) and in driving condition A ($p < 0.05$). This analysis was made on the total errors of each group for the entire vigilance session. Figure 1 shows the mean number of errors (missed signals) for subjects in each of the conditions.

It is apparent from Figure 1 that subjects in the control group (Con) performed better on the vigilance task than subjects in the other groups. There was very little difference in the performance of subjects in driving condition A (DC-A) and driving condition B (DC-B). In the mental fatigue group (MF) the fatigue effects were most apparent.

Although the primary concern in the study was with total errors and not with pattern of errors, data were analyzed to determine if a vigilance decrement had occurred in any of the groups. It was found that no decrement had occurred in the performance of control subjects or subjects exposed to the two driving conditions. However, a typical vigilance decrement did take place in the performance of subjects exposed to the mental fatigue condition before testing. This was unexpected because of the reward system used and because of the short mean intersignal interval used.

The mean number of errors made by subjects in the various groups in target detection are shown in Figure 2.

Statistical comparison of the number of errors made by subjects in the different groups showed that the subjects in the control group had significantly fewer errors than subjects in the mental fatigue group (p 0.01) and driving condition B (p 0.05).

It was possible for a subject to make two types of errors in the target detection task. A subject could report that no target was present when actually one was present (Type A error) or he could report that a target was present when there was no target (Type B error). In Figure 2, the two types of errors have been combined. However, analysis of the frequency of the two types of errors revealed an interesting pattern. It was found that the control group made significantly fewer of the Type A errors than did the

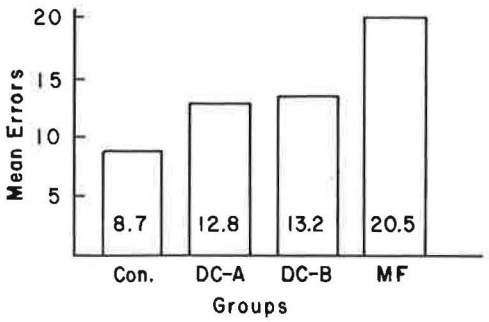

Figure 1. Mean number of errors in vigilance task for subjects in each group.

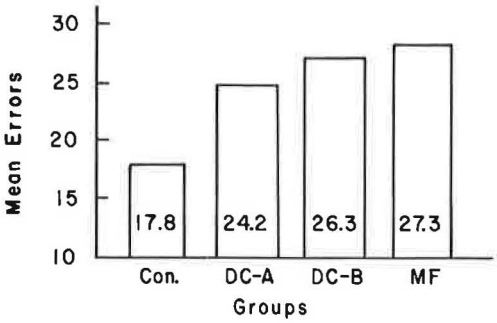

Figure 2. Mean number of errors in target detection by subjects in each group.

subjects in the mental fatigue group. However, differences between the other groups were not significant. In the case of Type B errors, however, subjects in the control group made significantly fewer than subjects in each of the other conditions.

Investigations dealing with fatigue ordinarily follow one of two types of procedures. In one case, subjects perform on a task and will continue, typically, for some period of time. During the session, performance measures are obtained on the primary task and possibly on subsidiary tasks. Ordinarily in fatigue studies of this type, subjects are assumed to be rested before beginning the session. A second type of fatigue study involves testing subjects, who have been fatigued before testing, on some form of performance measure. Examples of this type study are those that have been concerned with the effects of sleep deprivation on some performance measure. The study reported here also falls into this latter category. Obviously, both types of investigations can help in determining the effects of fatigue on driving. As pointed out by Crawford (2), 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. In most investigations concerned with fatigue and driving, however, studies of the first type, in which measures of performance were obtained as the subject drove an automobile or automobile simulator, have failed to reveal significant performance decrements.

In the present investigation, exposure to several conditions that were assumed to be fatigue inducing, resulted in modification of performance on both vigilance and target detection tasks. However, as is the case in most fatigue studies, it is difficult to state whether performance modification was due to changes in motivation of the fatigued subjects or due to more direct physiological changes.

CONCLUSIONS

Within the limitations of the conditions of this investigation, the following conclusions may be drawn:

1. Because vigilance and target detection performance are integral parts of operator performance, this performance will be most seriously affected by prolonged mental operations, which results in mental fatigue, and somewhat less affected by skill fatigue.
2. Vigilance performance and target detection performance both appear to be relatively sensitive to fatigue.

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