MONOTONY EFFECTS OF THE WORK OF
MOTORMEN DURING HIGH-SPEED
TRAIN OPERATION

Toshio Endo and Kazutaka Kogi

Laboratory of Work Physiology, Railway Labour Science
Research Institute, Kokubunji, Tokyo, Japan

The results of investigations done in 1965, 1966, and 1972 on the work-load of motormen of high-speed trains operating on railroads with maximum speeds of 210 km/hr were compared in an attempt to discuss the physiological implications of the driving task. The driving time of a 515 km section was 4 hr in 1965 and was lowered to 3 hr 10 min since 1966 for the fastest super-express trains. The mean heart rate was maintained around 80 beats/min during the entire driving period in 1965, but declined gradually in 1966 or 1972. Although in 1966 the operations at constant high speed appeared to favor cerebral activities, drivers in the 1972 investigation not only showed lowered perceptual and choice reaction performances but also experienced significant increase in errors in detecting signal tones given as a subsidiary task. Polygraphic recordings in 1972 indicated that drivers sometimes fell into drowsing of short duration intermittently, accompanied by temporary drop in heart rate, absence of controller action, and increase of detection errors. These effects were dominant in periods after 90 min of driving. The need to reduce the monotony effects during underloaded train driving is suggested.

In recent times, skills involved in railway vehicle driving have greatly changed, in particular due to the use of automatic train control systems which are a form of technological innovation being increasingly used in almost all branches of industry. The effects of the new systems are compounded because they create completely new areas for the development of occupational skills which workers will develop over long periods of time. In addition, the problems of train driving differ from those of other automated occupations in that it is linked with an awareness of the high risk of being the operator of a fast-moving train and continuous vigilance requirements of the driver (Grant, 1971). While automatic train control, requiring the use of electric railcars and cab instrumentation for signal
decoding and display, has resulted in increased train speed, corrections during operations remain very few and speed of reaction to a situation is not so critical as in driving ordinary trains or in operating a vehicle in highway traffic. Though the vigilance requirements and the high speed seem to result in additional loading, it is the effects of monotonous driving situations that are becoming predominant.

The high-speed train service (Shinkansen) has been in operation for more than 10 years since October 1964. Investigations on motormen's workload have revealed that their reactions are not only related to the train speed and changing environment, but tend to produce a decline in general alertness (Hashimoto, 1964; Hashimoto et al., 1964, 1966). This is apparently associated with physical inactivity and stableness of the driving situation (Kogi, 1968). It is also well known that a driver of a vehicle in a stable environment easily becomes accustomed to a condition that is similar to habituation to inspection tasks (Prokop and Prokop, 1955; Schwab, 1957; Niebeling et al., 1967; Böcher, 1968; Yoss, 1969). As a result, accidents or near accidental events due to railway drivers falling asleep are not unusual (Hashimoto, 1968; Hildebrandt et al., 1974; Kogi and Ohta, 1975). It has been suggested that the effects of mental strain of driving may not be measured on the basis of load-response relationships, but rather by analysis of the deterioration of skilled performance, including fine behavioral events (Bartlett, 1953; Crawford, 1961; Grant, 1971). However, the relation between mental strain and effects of continued vigilance is not clear yet.

In the context of occupational driving work, it is assumed that monotony may influence a man operating a train at a high speed as the result of long-term adaptation to the task. It is the purpose of the present paper to discuss the physiological implications of the high-speed train driving by comparing the results of a series of investigations and presenting evidence of fine changes in performance capacity.

EFFECTS OF CONTINUED DRIVING

Table 1 summarizes the outline of investigations conducted by our laboratory on the workload of motormen driving a Shinkansen train with maximum speeds of 200–210 km/hr. The first study in 1963 dealt with experimental running on a 26 km model section at different speed levels. Subsequently, three investigations were undertaken under almost the same conditions on workload of motormen driving between Tokyo and Osaka (distance of 515 km) based on three types of schedules. Schedules I and II consisted of continued driving on the fastest type of super-express train (Hikari) with only two stops in-between and a drive on the second fastest type of super-express train (Kodama) with stops at every station, the latter stopping over in Shizuoka or Nagoya for about one hour. The Tokyo-Osaka trip on the Hikari by schedule I and Kodama by schedule II
Table 1. Outline of the investigations on workload of the motormen of the high-speed train system.

<table>
<thead>
<tr>
<th>Item</th>
<th>Research period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1963</td>
</tr>
<tr>
<td>Line</td>
<td>Model section</td>
</tr>
<tr>
<td>Objective</td>
<td>Effects of 200 km/hr driving and reiterated drives</td>
</tr>
<tr>
<td>Conditions</td>
<td>100, 150, 180, and 200 km/hr in the 26 km section</td>
</tr>
</tbody>
</table>

* A resting period of 1 hr; +, A resting period of 3 hr; **, An overnight stay at a lodging house of 12–14 hr.

took place in the afternoon and the return trip was made the next morning, with the Kodama following schedule I and the Hikari schedule II. The third schedule was a return trip of two Hikari trains on the same day. The Tokyo-Osaka trip started in the morning and the return drive was made following a rest period of about 3 hr. Schedules I and II were similar to actual rotation of drivers schedules, while schedule III was experimental. Although Hikari trains operate normally by the two-driver system, alternation being made about half way, all the trains under investigation were operated by a single driver throughout the whole section. Kodama trains are always operated by a single driver.

Figure 1 compares the mean heart rate levels for different track sections for six drivers of the super-express trains for the years 1965, 1966, and 1972. The driving time covering the 515 km section was in 1965 4 hr for the Hikari and 5 hr for the Kodama, but in 1966 and 1972, it was reduced to 3 hr 10 min for the Hikari and 4 hr for the Kodama. Interruptions during the Kodama run took place approximately two-thirds of the total driving time. Four months after the beginning of the system in 1965 when unstable roadbed conditions demanded increased caution, the mean heart rate level was maintained at around 80 beats/min through-
out the driving time. This is in contrast with the gradually declining trend of mean heart rate for 1966 and 1972. The decline was distinct in the latter half of the 3-hr Hikari driving.

Fig. 1. Heart rate levels of six drivers on high-speed super-express trains for different track sections in 1965, 1966, and 1972. Means and standard error ranges of heart rate measurements while running on each section are indicated. The 515 km line between Tokyo and Osaka is divided into six sections.

Fig. 2. Variations of the means and standard error ranges of the critical flicker frequency during a two-day trip on high-speed super-express trains for the years of 1965, 1966, and 1972. Each value corresponds to measurements of six drivers obtained at intervals of about 30 min. The Tokyo-Osaka trip was interrupted at Nagoya, and the return trip in the next morning was without any interruptions.
Figures 2 and 3 show for the three investigation periods, the variations of the critical fusion frequency of flicker, which was measured repeatedly before, during, and after driving. The fusion frequency was measured three times at each measurement by the descending method using a rotating sector, and the average was taken as the fusion frequency. The figures show the means and standard error ranges, each value corresponding to measurements of six drivers obtained at intervals of about 30 min. Measurements on board trains were performed during train stops or during running while a foreman driver took charge of monitoring. Results for a two-day return trip (schedule II of Table 1) are indicated in Fig. 2, and those for a one-day return trip (schedule III) in Fig. 3. In 1965, the fusion frequency of flicker decreased markedly, especially on the return leg. In 1966, however, when the driving time reduced by one hour, the decline was less dominant, presumably due to stimulations by persisting high speed and reduced time (HASHIMOTO et al., 1966). In 1972, when motormen seemed to have adjusted well to the high speed and the system was quite stable, the lowering of the fusion frequency was again very remarkable, especially on the return leg, to reach a level as low as that of the 1965 investigation. Although the critical flicker frequency showed an initial rise immediately after the start of driving, indicating that driving had a stimulating effect on drivers, it was soon followed by gradual and consistent decline in value. The difference between the curve for 1966 and that for 1972 is clear in both of Figs. 2 and 3.

Figure 4 gives the cumulative frequency distributions of 120 4-alternative
choice reaction times of six drivers for the return leg running of schedule I of 1972. Measurements were conducted just before the start and 1 and 2 hr later during stops at each station. At each measurement 20 reaction times were serially measured while the subject had to push one of four keys corresponding to a numeral presented. Longer choice reaction times were more frequent after 1 and 2 hr of driving than before start. The distribution pattern was significantly different between the pre-driving curve and that after 1 hr, the chi-square value being 39.97 for the degree of freedom of 9 and significant at the 0.01 level. The difference between the distributions pre-driving and after 2 hr or between those after 1 and 2 hr was not significant.

These results suggest that the cerebral activity level tended to decline consistently after about 1 hr of super-express train driving, which became more dominant in 1972 than in 1966. Since there were no remarkable differences in driving strain between the two years of investigation, the more distinct decline in 1972 may not be solely attributable to the effects of the strain. The decline observed may thus be viewed as an indication of the monotony effects of train driving under well-acclimated conditions. That the increase of subjective fatigue symptoms was seen mainly for general dullness and not for other conditions, such as irritability (HASHIMOTO et al., 1972), may support this view.

**PERFORMANCE CHANGES DURING DRIVING**

In order to examine the possible monotony effects of the high-speed train driving, fine changes in drivers' performance were studied in 1972 by continuously recording responses to a subsidiary auditory task given during the driving of a train. The task involved detecting a 1,046 Hz tone given at random among 784
and 1,310 Hz tones, each tone appearing at intervals of 2 to 4 sec. When the driver detected the signal 1,046 Hz tone, he responded by means of a footpedal switch. All responses were recorded together with autonomic reactions, electro-oculograms, and major driving operations.

An example of changes in autonomic and performance parameters is given in Fig. 5. In the second hour of driving following the two-minute stop, the heart rate level decreased slightly, with the frequency of galvanic skin reflexes increasing to some extent. At the same time, from around the 80th min, the driver began to yawn and change his sitting position very often. The number of errors in detection of the subsidiary tone signals indicated by black points in the figure also increased from around the 80th min until the 120th min. During this period, the driver became very drowsy and tended to manipulate the speed controller less frequently. The same driver’s polygraphic recording is shown in Fig. 6 for the period around the 112th min. This recording is evidence that the driver fell into intermittent drowsing of short duration. The electro-oculograms indicate repeated closing of the eyes lasting for about 5 to 10 sec, accompanied each time by a temporary heart rate decline. In absence of controller actions, increased fluctuation in train speed as well as increase in errors in detection of the subsidiary auditory task occurred.

Figure 7 shows the changes of mean percent detection of the subsidiary tone signals given during the whole driving time for both the Hikari and Kodama.
The data were obtained in 1972 for six drivers. A remarkable decrease of the detection rate is found for both the Hikari and Kodama in the later periods of driving, in particular in periods exceeding 90 min. Very large fluctuation of the

![Graph showing polygraphic recording](image)

Fig. 6. A polygraphic recording showing frequent drowses of the same driver as in Fig. 5. HR, cardiotachogram; GSR, palmar skin resistance; EOG 1, vertical electro-oculogram; EOG 2, horizontal electro-oculogram; †, detection of a subsidiary tone signal; ‡, omission of responding to a tone signal.

![Graph showing percent detection](image)

Fig. 7. Percent detection per 5 min of subsidiarily given tone signals for each of six drivers during the whole period of driving two different kinds of the high-speed super-express trains. The Hikari had 2 intermediate stops, and Kodama had 10 stops, the drive being interrupted at the 7th stop with an interval of about 1 hr. Data from the 1972 investigation.
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Detection performance was seen. At least in several cases where the detection rate was around 50% or less, the driver was apparently very drowsy and was seen closing his eyes for a while. Such a condition was found at around the 135th min of the Hikari drive and the 60th min of the Kodama drive of subject B, and at around the 98th and 115th min of the Kodama drive of subject E. No such cases were encountered during the investigations in 1965 and 1966.

The effects of the kind of drive, time, and subjects on the subsidiary detection performance were studied by performing an analysis of variance. The results are shown in Table 2 for the first 140 min of the Hikari and Kodama drives and for the first 75 min period of the first and second Kodama drives with a 1 hr pause interval. The analysis shows that the kind of drive, time, and subject variability were significant. The interactions between the independent variables were not significant for the first drives of Hikari and Kodama, but significant for the data of the first and the second drives of Kodama. It is suggested that some subjects tended to show lower detection performance than the others, that the driving duration had significant effects on performance capacity, and that drives on Hikari with only two intermediate stops were more subject to such effects than Kodama driving. It is also implied that a resting period of about 1 hr could not prevent the accelerated decrement of the detection rate after it.

DISCUSSION AND CONCLUSION

Summarizing the results, it can be reasonably assumed that the new organization of the driving task including intra-cab vigilance requirements did not overcome the effects of monotonous environment of high-speed train driving. The effects were so pronounced as to produce functional decline in both autonomic and cerebral parameters, which, in certain instances resulted in recurring drowsiness. The possible monotony effects was indicated as due to the marked decrement of the alterness level of drivers repeating high-speed drives on the 26 km-
long model section (Hashimoto, 1964; Hashimoto et al., 1964). Such effects would be associated with the automatic train control system, so the driver only accelerates the train by operating the main controller, brakes from time to time to maintain the speed just below the given upper limit, and stops the train at stations after the speed reducing to less than 30 km/hr, automatic braking being put into action when the speed exceeds the given display limit in the cab. It seems evident that the effects of a monotonous driving task would become gradually dominant as a result of the continuation of this kind of task for a very long period.

If the underloading of a driver is actually a factor in development of fatigue, it appears that it is counterbalanced to some degree by additional vigilance requirements and the stress the driver undergoes while driving at high speed along the track (Grant, 1971; Hashimoto et al., 1966). Such a stress is always present, and may indeed have some stimulating effects. This may be one of the reasons why the effects of underloading were not properly assessed by our 1965 or 1966 investigations. We should also take into consideration the relatively moderate changes of physiological functions during high-speed train driving. Such changes are somewhat more explicit than observed in usual industrial vigilance tasks in factories or control centers, but are not as large as has been observed in city traffic situations where frequent manipulation is needed (Hashimoto, 1969; Bestvater et al., 1970; Grant, 1971; Kogi and Saito, 1971). The monotony effects of high-speed trains discussed in this paper are presumably associated with these facts (Kogi, 1968). It should be also noted that the cues which are critical to the driver are fewer after several years of experience than at the beginning of a new system. The marked and long-lasting reactions of drivers in an emergency on the high-speed train (Kogi et al., 1968) may be related to the generally in-activated physiological conditions of the driver in ordinary situations.

Whether the formulation of the motormen’s task to prevent the effects of underloading and monotonous environment will be possible remains to be seen. Perhaps more advanced centralization of operations which would reduce the driver’s own control over the train are not desirable. Though at present there are no high-speed trains running at night between 0:00 and 6:00 and the effects by irregular night drives reported for usual train drivers (Aoyama and Ohta, 1971; Foret and Lantin, 1972) are not manifest, the overnight trains would raise more serious problems and therefore should be avoided. Single driving should also be reassessed. It is already argued that driving through many tunnels built in the western part of the present Shinkansen line provide new health problems of the drivers. Various attempts are needed to evaluate the drivers’ loading. Such attempts, however, should be based on the assessment of the general stress situations and the analysis of the driving skills involved. Since it is likely that the more advanced form of train control systems will increase the monotony effects, an urgent need must be pointed out of figuring out the task of the motormen from standpoints of long-term effects and health.
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