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The SIFA Train Function Safety Circuit

I. Vigilance and Operational Practice in Psycho-physiological Analysis*

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Summary. The SIFA is a paced secondary motor task, which is expected to monitor the train driver's 'fitness for service' on engines of the German Federal Railway. Disregard of the device leads to an emergency braking. As, in contrast to a true vigilance test, the SIFA cycles are characterized by paced and clearly supraliminal signals; we presumed that adequate operation of the device does not necessarily correspond to sustained attention of the driver. This study shows how the SIFA can be effectively tested under laboratory conditions. Our design allows the reduction of vigilance as evident from the EEG, and a controlled investigation of the possible connection between different modes of SIFA operation, physical load, and different levels of vigilance. Finally, some sample registrations show that phases of low vigilance do occur and do not prevent adequate operation of the device. It is suggested that SIFA-trained persons can operate the SIFA in phases of low vigilance because a specific central nervous arousal reaction enables them to raise their level of vigilance in synchronisation with the SIFA cycles to a degree that makes the successful performance of this task possible. A future report will provide a quantified analysis of the correlation between vigilance reduction and SIFA operation.

Key words: Vigilance - EEG - Secondary motor task - Occupational monotony - Central nervous arousal

Introduction

With the introduction of one-man-service on modern high-capacity tractive units, some railway companies have realized the necessity of installing a monitoring device taking the shape of a paced secondary (motor-) task. The

*The SIFA has sometimes been referred to as a VMD (Vigilance monitoring device), see references

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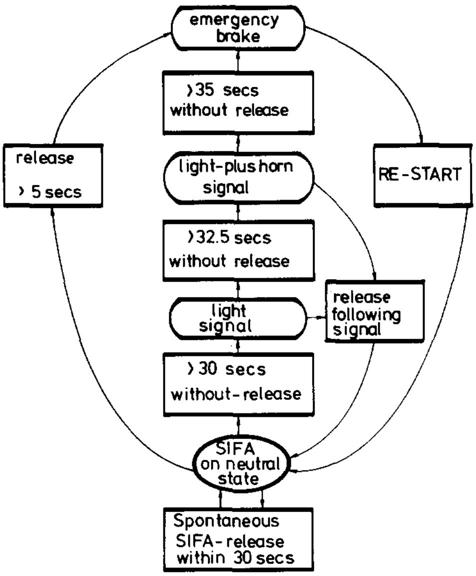

Fig. 1. Diagram of SIFA cycles. The driver keeps any one of the SIFA controls depressed for up to 30 s (neutral state). Spontaneous release is possible within 30 s and up to 5 s, release for longer than 5 s activates the emergency brake system (*left*). After 30 s, a lamp-signal, after 32.5 s, an additional horn-signal demands release of the controls. After 35 s without release, the train is automatically stopped (*center column*). Spontaneous release or response to a signal both start a new SIFA cycle

German Federal Railway (Deutsche Bundesbahn) today employs the safety circuit "SIFA", the correct operation of which is regarded as a guarantee for the train engineer's "fitness for service", i.e. his alertness and preparedness for crucial operations. The modern SIFA is a sophisticated step beyond the traditional safety-deadman-circuit. Control elements are one foot pedal and several levers/buttons in various parts of the driver's cabin. Whereas the traditional deadman handle had to remain constantly weighted—which allowed a man, a dead body, or any object of sufficient weight to carry out the appropriate function—the SIFA handles have to be released at least once every 35 s. The SIFA-functions are detailed in Fig. 1.

As far as the train driver's physical presence and readiness for simple motor activities are concerned, the SIFA no doubt fulfills the claim of monitoring the "fitness-for-service" of train drivers. But "fitness-for-service" would—under working conditions described above—include the aspect of long-term attention. If the SIFA claims to monitor the train driver's alertness via a test of paced motor activities, this claim raises the question, to what extent an adequate performance of a motor task can serve as an indication of mental activation, or, the other way round, if these two realms of activity may not be dissociated under certain conditions. If this is the case, the monitor function of the SIFA safety circuit would be seriously impaired.

The term "vigilance" is commonly employed in connection with the decline in performance resulting from middle- to long-term observation of sparse, random, and only slightly supraliminal signals under monotonous conditions. Since Mackworth (1948), a variety of empirical designs have been developed that allow the postulated decremental function of vigilance to be tested (for a survey and critical discussion see Mackie 1977). The decline of performance in observational tasks is measured in these tests as a function of stimuli characteristics, especially of slight specific environmental changes. It should be noted that the SIFA safety circuit does not meet the demands of such a vigilance test, first, because the intervals of required response are not randomly distributed, but paced, and second, because the signals–especially the horn signal–are not marginally supraliminal, but are unambiguous alarm signals.

It has long been known from experimental psychology that subjects are able to register changes of certain internal variables within a certain range and counteract a threatening decline in performance. The decline in performance in vigilance experiments may be a function of the subject's perception and processing of the experimental situation itself (Nachreiner 1977). The electroencephalogram (EEG) has been found to be the physiological parameter, which allows an optimal registration of those internal changes which–on the waking-to-sleep-scale–determine the efficiency of the central nervous system. Specific with regard to vigilance are both the EEG-frequency within a range of 3–30 Hz and notably slower changes of potential, which correlate with sensory or motor events (event-related phasic changes of potential). The problem that empirical vigilance research still has to face is how to register any other (task and environment related) factors with corresponding accuracy and "along" with the EEG–i.e. under conditions which allow a technically flawless EEG to be conducted. It is obvious that the actual experimental set-up demands concessions either at the expense of operational relevance or at the expense of experimental control (Mackie 1977). Investigations of real-life vigilance tasks rarely allow a high degree of experimental control, whereas laboratory experiments raise the problems of validity of the task and proper assessment of motivational factors.

Methods

Preliminary Studies

By trying to take into consideration the present problems of vigilance research, we tried to design and optimalize an experimental set-up which would:

- induce a marked decline in vigilance,
- allow measurement of the EEG as a physiological vigilance parameter, and
- provide perfect simulation and registration of SIFA operation.

We could use some information from studies devoted to error frequency, fatigue, and night- and shiftwork problems of railway employees (Hildebrandt et al. 1973, 1974a, b; Rutenfranz et al. 1974, 1975). These studies grew out of an expertise for the Federal Secretary of Traffic and Transport (by the same authors, listed as Binding et al. 1972). With regard to the operation of SIFA, the expertise, using a very large sample of railway drivers, shows that acoustic warnings are not very frequent in everyday practice, and compulsive brakings extremely rare. Proceeding from all available information, we conducted a series of preliminary studies, all of which helped to shape the final set-up as described below. These included:

- interviews of train drivers,
- observation of train drivers under working conditions,
- long-term registration and analysis of SIFA-operation as performed by train drivers during normal working hours,
- EEG-controlled motorcar driving experiments with a simulated SIFA device, and
- laboratory experiments with different set-ups in order to optimalize a final systematic investigation.

The "interviews" were not standardized. About 50 train drivers were asked questions in an open exploration; subjects who were little inclined to discuss matters which they apparently felt fell under 'professional taboo' were questioned less intensively. The most important results shall be briefly summarized. Asked to rank the main stress factors during working hours, the drivers mentioned the consequences of shift work in the first place, closely followed by monotony problems. All subjects agreed that the night-time driving of high priority trains, such as long distance freight trains or car sleeper trains, which are run at constant high speed for several hours on end, was particulary strenuous.

According to the interviews, deep sleep rarely occurs, whereas states of drowsiness are fairly frequent. Questioned about the operational practice of the SIFA device in phases of lowered vigilance, some subjects reported situations, during which the driver displayed symptoms of sleep such as closed eyelids, snoring, 'dropping of the head', but was still able to operate the mechanism spontaneously a few times before the first horn-signal occurred. Further, most instances of emergency brakings do not occur at travel speed but during slow driving and switching manoeuvers, which make it more difficult to attend to the device. Most drivers preferred to operate the device by means of the foot-pedal (some subjects specified that foot operation allowed a more stable rhythm to be maintained). Furthermore, all subjects reported a 'training effect' in the operation of the SIFA device which, after only a couple of days, helped them to operate the SIFA 'instinctively' and, after several months, made the task 'second nature' to them.

The data gathered from "observations in the field" corroborate the information obtained in the interviews: Most drivers prefer the SIFA foot pedal, which is occasionally operated with both feet, but more often alternately. This practice seems to strain the lower extremities considerably and to fix the driver's body in a quite uncomfortable position. This observation agrees with the fact that during the interviews especially older drivers complained of backaches and legpains after long distance travels. The varicose veins and chronic ailments in the realm of the lower extremities from which some of them suffered were explicitly attributed to prolonged SIFA operation. Most train drivers tend to keep a fairly stable rhythm of SIFA operation, which is maintained even when the driver is concentrating on his main task. These self-paced operational patterns vary individually, but most drivers prefer intervals of medium duration between 10 and 20 s (Meinzer 1976; Meinzer et al. 1976; Peter 1976; Peter et al. 1976; Fruhstorfer et al. 1977).

We optained additional information by conducting "car driving experiments", which were devoted to the exploration of driver's fatigue and highway monotony, and included several runs with SIFA simulation. Similar investigations on rail engines were hitherto impossible due to technical problems as well as lack of support from railway authorities. The experiments included night-time driving on monotonous routes under EEG-control. In spite of objective signs of phases of lowered vigilance as shown in the EEG and measurement of eye blink duration, and in spite of a marked deterioration of driving performance as registered by the experimentor and recorded with a built-in camera, the SIFA device was satisfactorily operated even by untrained subjects. Results from these experiments have already been reported in some detail (Pfaff et al. 1975, 1976; Pfaff 1976; Fruhstorfer et al. 1977; Meinzer et al. 1978).

In a series of "laboratory tests", we tried to find the most suitable set-up. Within the short space of a laboratory experiment we had to reduce our subjects' vigilance to a measurable degree without making the operation of the SIFA device impossible. It is evident that both the performance of the paced motor task of SIFA in full alertness as well as a lowering of vigilance which would make this operation impossible would have contributed nothing to an understanding of the mechanism that presumably allows train drivers to attend to the SIFA during or alternating with phases of reduced vigilance. We tried different designs using a variety of volunteers available, including ourselves, and later a number of professional train drivers. Performance and vigilance of the same subjects were tested with different set-ups for better comparison. As we expected, a silent chamber, which allows for a high degree of sensory deprivation, proved the most suitable for the reduction of vigilance essential to the experiment. We settled for a total of 160 min of experimentation time. A considerably longer period would have resulted in superfluous stress on too many subjects, a considerably shorter time would not have resulted in a sufficient reduction of vigilance. After different attempts to provide a 'primary task', we decided to use a design that required exclusive operation of the SIFA. We found it useful, however, to introduce a 'sham task' in the introductory phase of the experiment that would ensure a uniform level of concentration and adjustment to the experimental condition. The final experimental set-up is described below.

Hypothesis. The earlier studies mentioned above as well as our interviews and observational investigations draw attention to a major contradiction: on the one hand, emergency brakings due to a failure to operate the SIFA seem to be extremely rare, on the other hand reduction of the drivers' vigilance in high priority long distance service seems to be fairly common. Theoretical considerations and results from the preliminary studies suggest that the SIFA does not constitute an efficient vigilance monitor. This expectation led to the hypothesis that, in spite of the occurrence of phases of noticeably reduced vigilance down to stages of light sleep, the SIFA device is successfully operated. This mechanism may be conditioned, because both the SIFA signals, especially the noisy horn signal, and a threatening emergency braking constitute aversive stimuli to the driver. The mechanism might therefore take the shape of a rhythmical physiological arousal reaction, which would be synchronized with the SIFA cycles and would allow rhythmical performance of this paced task, thereby interrupting but not preventing phases of low vigilance. Our hypothesis implies that this mechanism can be reproduced under laboratory conditions if sufficient reduction of vigilance is induced and the operation of the SIFA is made the main task of the subject.

Results

Final Design

We succeeded in finding an experimental set-up which permitted a measurable reduction of vigilance and a record of SIFA operation (Fig. 2). Sensory deprivation by means of a silent chamber quickly reduces the subjects' vigilance. The specific level of vigilance can be ascertained by means of EEG registrations. A

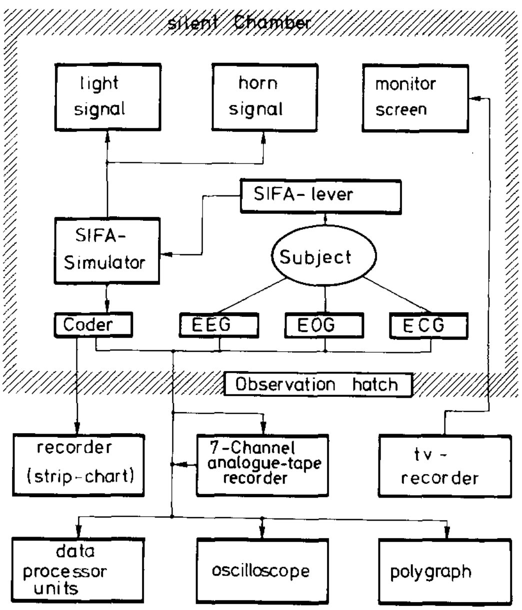

Fig. 2. The final experimental set-up. The subject operates a SIFA simulator with an original SIFA-horn (85 dBA, 1.000 Hz) in a darkened "*camera silens*". SIFA cycles follow the pattern detailed in Fig. 1. Bioelectric signals (EEG, ECG, EOG) and the precoded SIFA events are registered together and stored on analogue tape. Data reproduction is possible by means of a strip-chart-printer, oscilloscope, polygraph, or via data processor. A small monitor screen allows the reproduction of videos for the introductory runs

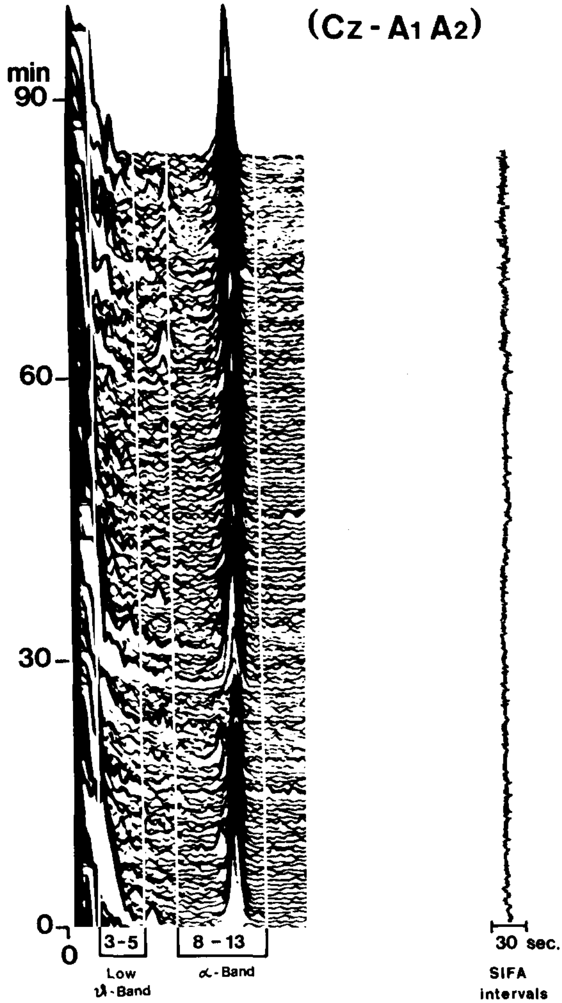

Fig. 3. EEG and SIFA operation. Results from the Fast-Fourier-Analysis. Power spectra left, calculated over a window of 30 s. In spite of massive low ϑ-activity (indicated, far left) corresponding to sustained phases of low vigilance, the SIFA is correctly operated in intervals well below 20 s and at a fairly stable rhythm (right)

correlation of vigilance and data of SIFA operation is achieved by a simultaneous registration of the data of SIFA operation and the EEGs. An ECG allows the introduction of cardiovascular activity as an additional parameter for physical load[1]. An original SIFA pedal connected to a SIFA-cycle simulator allows the simulation of actual SIFA practice. Subjects have to operate the SIFA with closed eyes. This is controlled by an EOG in order to avoid artefacts. A video-screen allows video-recordings to be shown during the introductory phase of the experiment. The distinction between several uneventful recordings can be used as a sham task, which demands the subjects' close attention, thereby reducing their vigilance, and at the same time accomodating them to the operation of the SIFA under experimental conditions. All data can be stored on analogue tape and can

[1] This important parameter will be investigated in a future study devoted to heart-rate and SIFA operation

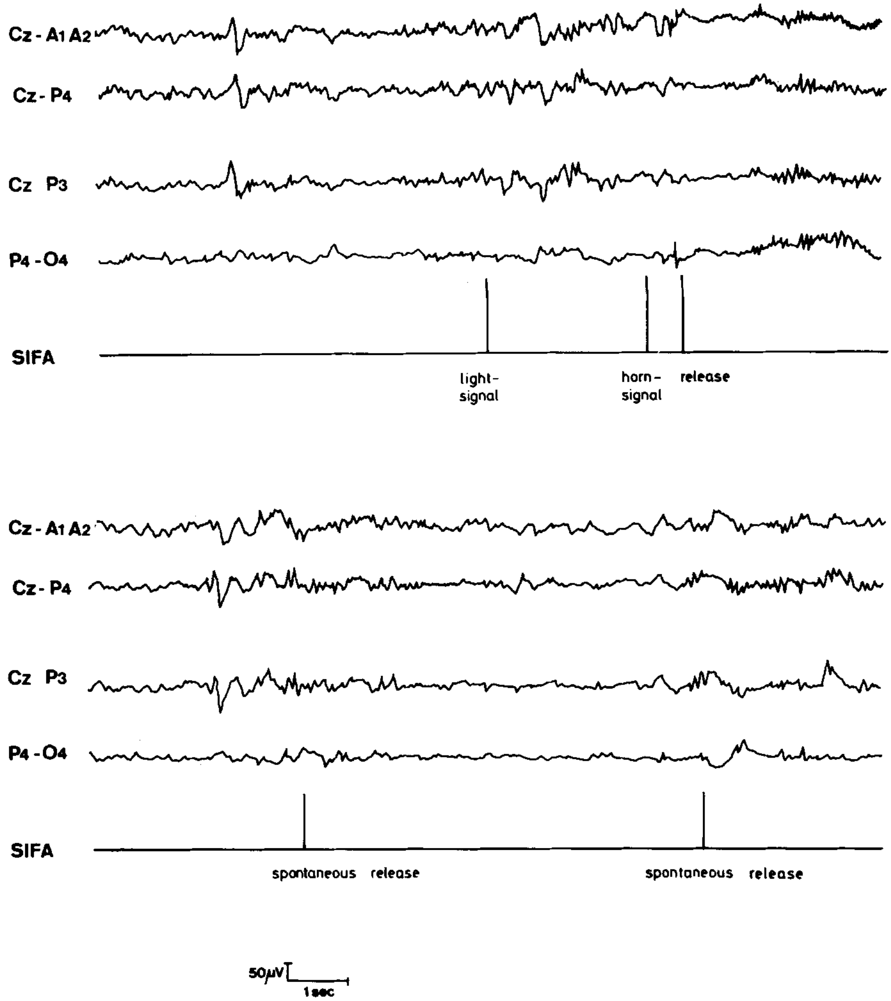

Fig. 4. Original EEG polygraph plottings showing central nervous arousal corresponding to SIFA operation. Example *above:* A SIFA warning interrupts a phase of light sleep marked by low frequency/high amplitude ϑ-activity and distinct sleep spindles. The horn-signal triggers an arousal reaction with initial β-activity (14–30 Hz) of increasing amplitude, followed by α-activity. *Below:* The same arousal pattern is discernible in connection with spontaneous releases, following a phase of light sleep as just described (*bottom, left*) and a deep subvigil stage (*bottom, right*; high amplitude ϑ-activity 3–5 Hz) respectively

be processed either directly or from tape. The test-runs show that the subjects' vigilance is quickly and measurably reduced, while the SIFA is still being operated. Sample registrations show that the apparatus provides important insights into the functioning of the mechanism of SIFA operation in phases of low vigilance.

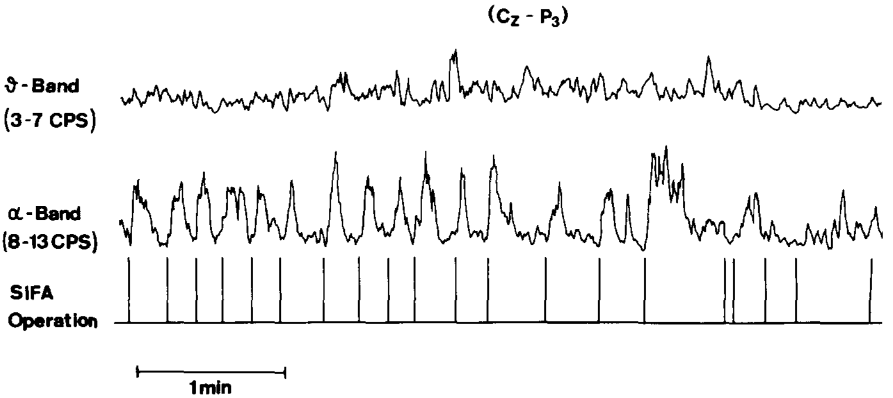

Fig. 5. Original print-out of ϑ- and α-band EEG amplitudes, analogue filter values. SIFA releases (*bottom line*) are indicated by vertical strokes. It is noticeable that the increase of α-activity during the course of the central nervous arousal reaction closely corresponds to the spontaneous SIFA releases but reaches a maximum only several seconds *after* a release

Evaluation of Sample Registrations

Different methods of evaluation were possible. We used a computed Fast-Fourier-Analysis as well as an analogue filter bank, which allowed a continuous ascertainment of the dominating EEG frequency at any point of time given. That correct SIFA operation is possible in spite of reduced vigilance is shown in Fig. 3. The subject's EEG frequency patterns were calculated sequentially by means of a Fast-Fourier-Analysis, extending over a range from 0–32 Hz and using a window of 30 s, thereby breaking up the total experimental time into 180 segments. The resulting power spectra were automatically plotted one above the other and juxtaposed with the intervals of SIFA operation, which were represented along the same time-axis, thus allowing an immediate comparison of EEG frequency patterns and SIFA performance for each segment.

The subject's power spectra plottings show a high proportion of ϑ-activity indicative of deep subvigil stages down to light sleep, nonetheless the subject maintains a fairly stable and fast rhythm of SIFA operation (with operation intervals far below 20 s) and does not receive a single warning .

The physiological mechanism that allows the correct execution of the manual task of SIFA operation is illustrated by Fig. 4, which shows original polygraph plottings of the four EEG leads registered according to the international 10/20-system, together with the SIFA-events which were recorded on a fifth channel. The two examples, taken from the same person, illustrate processes which seem to be typical for situations in which EEG patterns indicative of reduced vigilance coincide with the SIFA-events. The first example (Fig. 4 above) shows a SIFA warning during a phase of sleeping activity indicated by characteristic low frequency ϑ-activity of high amplitude and distinct sleep spindles (σ-activity 12–14 Hz). This pattern is discernible during the 2.5 s of the lamp-signal and even after the beginning of the horn-signal. The horn-signal leads to an arousal reaction in the EEG with initial β-activity (14–30 Hz) of increasing amplitude, followed by α-activity.

The second example (Fig. 4 below) shows first a spontaneous SIFA release immediately following a light sleep pattern similar to the previous example. The EEG frequency pattern during the central nervous arousal reaction in connection with this spontaneous release is very similar to the pattern of the arousal reaction following the horn-signal (light sleep/followed by initial β- and than α-activity). The remaining SIFA-event, again a spontaneous release, follows a deep subvigil stage (high amplitude low frequency ϑ-activity 3–5 Hz), but, here still, the EEG-pattern-changes follow the description of the arousal complex, which begins shortly before the SIFA is operated.

Figure 5 shows a temporal synopsis of α-activity and the arousal reaction which was observed whenever ϑ-activity proceeds the operation of SIFA. Vertical strokes in the bottom line are SIFA-releases taken from the respective track of the polygraph printer, α- and ϑ-activities are represented according to the output of the analogue filter bank.

Discussion

While trying to test the efficiency of the SIFA train safety circuit as a paced secondary task serving as a vigilance monitor, we found that under laboratory conditions it was not worthwhile simulating a primary task, as this would have involved the difficulty of 'faking' a 'real life' task, and we would not have been able to ascertain, if the subjects' motivation actually concentrated on the 'primary' or the 'secondary' task. We therefore disposed of a 'primary task', which, under laboratory conditions, would have lacked the quality of 'real life' occupational situations, and concentrated on the simulation of highly monotonous working conditions. It soon became clear that sensory deprivation in combination with an introductory sham task would lead to a decrease of the subjects' vigilance which in turn would show if a simple paced manual task, such as the operation of the SIFA device, could work as a vigilance monitor.

This is not the case. The experimental set-up we developed succeeds in lowering the subjects' vigilance down to stages that make adequate reactions to unexpected stimuli extremely improbable. Nevertheless, the SIFA is operated without fail, i.e. without the concequence of emergency brakings which, under real life conditions, were intended to be the consequence of a train driver's decline of vigilance. Our results, obtained under laboratory conditions, corroborate results gained from observation and preliminary studies.

Our examination of the subjects' EEGs immediately before and after events of SIFA-operation indicate clearly that the SIFA device is not operated during deep subvigil stages or even light sleep, but during arousal reactions which, similar to the SIFA-signals themselves, occur rhythmically. Between the SIFA-events, the vigilance of the subjects often declines for several seconds down to stages of reduced vigilance, marked by the absence of α-activity and an obvious increase of ϑ-activity in the EEG. This not only shows that the SIFA cannot guarantee a train driver's 'fitness for service' and thereby ensure a high degree of safety in rail traffic, it also indicates that the operation of SIFA entails a high degree of physiological stress on engine drivers.

The results obtained so far do not allow general conclusions. The effect of training, cardiovascular load, and intra- and interindividual differences with regard to the operation of SIFA were not investigated in this study. A systematic approach, using the facilities of the experimental design described here, will be reported in a future study, which was conducted with a sample of experienced drivers. This quantified analysis will further substantiate our suggestion that the correct operation ot the SIFA device does not guarantee long-term attention of the driver, but rather constitutes an additional occupational stressor.

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