Assessment of mental load in an ergonomic approach

Brain activity in a simulated air traffic control task: a case study

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Introduction There is almost no epidemiologic research known in which the impact of automation on man is studied. Examples of unidisciplinary studies carried out in parallel, showed limited, even conflicting results between the different scientific orientations. Therefore, pathologic consequences which have been objectivated (as for instance nervous breakdowns, burn outs, increasing near-failures, error levels and other behavioral effects as well as some musculi-skeletal disorders) could not be confirmed by reliable effect-cause relationships. The delay between cause and the final result is too much to develop an effective prevention policy. The responsible authorities, each in their own discipline, tried to set up guidelines to improve health, safety, comfort and efficiency, and from their experience it seemed that a more multidisciplinary approach could be useful.

The contribution of ergonomics, which in its total approach is by definition based on multidisciplinary research, and participative principles have a scientific as well as pragmatic character. Indeed, the applied methodology seeks for knowledge of what happens in the existing work systems in which the man-machine-environment relations determine the final output. The ergonomic methodology we use, therefore includes the simultaneous measurement and evaluation of the external load (concerning the stressors in a system), the internal load or strain and the subjective experience of the worker.

Our basic model of mental load is similar to the framework used for physical load. We try to identify the stress variables within the task and the environment and link them to the reaction of the worker. To evaluate the resulting strain, we compare the obtained values of the strain parameters with the individual maximal capacity of the worker. In the case of mental load, the perception and evaluation of the task and the environment by the worker are more important than the objective features. Also in the output of the task some intervening variables are found, for instance the used strategy and the quality standard. Therefore, it is necessary that the worker himself gives information about the perception and evaluation of the work. We do this by means of an elaborate interview on the work spot itself immediately after the task has been finished.

One of the problems in this methodology, that we still try to improve, is the objectification of psycho-mental strain. We are still looking for an adequate parameter to quantify the reactions of the individual to the mental task. In the literature, few specific clues to the required information are found. We investigated the possibility of using the electro-encephalogram, i.e. the registration of electrical potentials in the human brain waves. Some features of this physiological parameter have been used in the past to establish a relationship between the task and the strain it causes, for instance components of the evoked potential such as the contingent negative variation. The use of the latter parameter however, needs an exact identification of the stimulus which attracts the attention of the subject and elicits the evoked potential. This is feasible in experimental settings where the tasks are very simple and the subject responds to single stimuli such as light flashes and sound. In a real work situations, there is little or no control over the nature and amount of information stimuli that the subject has to take into account. In order to adhere to our first axiom in ergonomic studies – measuring on the work spot itself following the normal course of work – we had to do with a more global approach in which we compared various sequences of work and a global measurement of the mental strain. So, we focused on changes in the frequency patterns of the electric potential, by means of a spectral frequency analysis. This case study on air traffic controllers should be regarded as an attempt to open the discussion on this topic and to arouse the interest from other scientific disciplines.

Aim The aim of the study was to obtain an objective registration of the changes in brain activity in relation to changes in mental load during air traffic control work using an Electro-Encephalogram. Simultaneously, measurements of heart rate, skin resistance, skin temperature were carried out and combined with the registration of the Critical Flicker Fusion (CFF) frequency and interviews before and after the simulated Air Traffic Control (ATC) task. In this way, we hoped to link the EEG-phenomena with the characteristics of the task and the other physiological and psychological test results in order to find some indications of a causal relationship.

Simulation The experiment took place in the simulation room of the Eurocontrol Research Centre at Bretigny sur Orge (France) where the environmental conditions are identical to standard control rooms used in air traffic control (sound proof, low ambient lighting – no day-light, air-conditioned). A real time simulation of the ATC task was provided by a software programme "Kennedy approach" (standard operating procedures for air traffic control, micropose, FAA 7110.66d). The programme was run on a Commodore CMB64 microcomputer using the systems standard colour graphics and speech synthesizer.

The programme provides a schematic Synthetic Dynamic Display (SDD) showing airways, airports, fixed obstacles such a mountains and restricted areas, and moving zones of bad weather. The aircraft is indicated by graphic symbols showing aircraft call-sign, type, direction of flight and height. A schematic Electronic Data Display (EDD) is also provided, giving aircraft identity, height, origin and destination of the flight. An aircraft may overfly the region, land at an airport or take off from an airport. Flight plans, flight rules and the destiny of traffic are according to the average situation of the area. The aircraft may report a fuel emergency and problems are indicated by a warning tone and flashing symbols on the EDD.

Each run of the programme took approximately 20 minutes. Varying levels of difficulty were attempted by choosing a more or a less complex area (with a higher/lower traffic density, frequent/infrequent bad weather conditions, more/less restricted areas). Experienced controllers take the view that moderate and high task levels are of compatible difficulty and require abilities to real air traffic control.

Subject One qualified air traffic controller with more than five years experience in this field, was recruited as a volunteer. The controller was a right handed male with no injuries or medical history likely to influence the results. Several learning sessions were carried out during the days before the experiment took place in order to familiarize the subject with the equipment and the measuring devices. In this way, the learning curve had flattened before the start of the experiment.

Procedure and measuring devices Although our main interest is in the electro-encephalographic registration, we will give here briefly the list of all measuring devices used during the experiment. The electro-encephalogram recorded form the scalp using Ag-AgCl electrodes located at the positions O_1, O_2, P_3, P_4 and C_3, according to the International 10-20 system. Scalp potentials were recorded on a MEDILOG 9000 multichannel ambulatory monitoring system and afterwards analyzed by a NIHON-KOHDE Trend Monitor in order to obtain a two-channel power compressed spectral array of the stored raw EEG, reflecting the distribution of frequency components over time (epochs of 10 seconds).
Heart rate, skin resistance and skin temperature were recorded at intervals of 15 seconds by means of the MEMOLOG 500 SYSTEM. We used three electrodes for heart rate measurements, one electrode placed on the right shoulder for skin temperature and two electrodes on the left fore arm to measure skin resistance.

Immediately before and after each session, a Critical Flicker Fusion test was conducted in the same test room. The measurements were done on two consecutive days. In all, three sessions of several exercises were carried out. On the first day, six exercises were carried out in the morning (total duration 1 hour and 42 minutes) as one continuous period of mental load. Before and after this session a rest period was planned during which the subject was sitting relaxed before the screen with closed eyes. On the second day, two sessions were carried out. The first was identical to the one carried out on the previous day and consisted of six exercises with rest periods before the first and after the sixth exercise. The second session, in the afternoon, was composed of only two exercises with a duration of 40 minutes, again including rest periods before and after the task.

Results Our registration of the electro-encephalogram shows some persisting patterns in occurrence of the different frequencies which might be linked to the independent variables of traffic constellation.

1. Changes occur in the amount of alpha- and beta-waves (frequencies of 8 to 12 Hz, and from 15 to 32 Hz).

2. There is little alpha-activity (8-12 Hz) during the first exercise of each session. alpha-activity bursts appear during the second half of the session each time followed by an increase of beta-activity (15 to 32 Hz).
3. An increase in difficulty (new level of exercise) shows more important activity in the beta-bands.
4. Comparing the three rest periods after the various sessions, results show contrary to expectation, that by closing the eyes the alpha-activity decreases after session II and even more after session III compared to the alpha-activity session one. The alpha-activity also appeared later in time from the moment the subject closed his eyes.

It should be mentioned that the controller, feeling exhausted, stopped the third session spontaneously after the second exercise.

Combining these observations with the information from the interviews lead to the following assumptions:

1. Functioning in a routine-way (e.g. during exercise 2 of the first and second session), indicated by the subject as less stressing, seems to be confirmed by lower brain activity in the beta-frequency bands. Adjusting to new elements in the working situation, as was simulated by the change in level of the exercise, shows more important activity in the beta-bands.
2. Brief moments of lost interest or fatigue are accompanied by alpha-bursts. Being aware of this drop of attention, the operator increased his mental activity which is reflected in increased beta-activity.
3. A posteriori, the lack of ability to relax immediately at the start of the rest period, shown as a decrease of alpha-activity during this epochs, could give an idea of the amount of mental load of the task.

Conclusion Although the study has been carried out on one subject in one particular simulation, some hypothesis has been developed in function of the obtained measures.

Our findings suggest that the evolution in alpha-activity and beta-activity could provide an adequate measurement of the mental strain, however, there are some shortcomings in the use of these parameters.

Firstly, not every individual shows alpha-activity in a state of awareness. Secondly, alpha-activity has been linked to a lack of visual fixation of accommodation. The influence of eye movements on the electric spectral pattern can mask effects of mental strain.

Nevertheless, we are convinced that research investment in this approach will lead to an acceptable way of measuring mental strain.

This study provides evidence that it is possible to conduct measurements of electrical activity of the brain in real life situation, even in difficult conditions (apparatus surrounded by electronic devices).

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