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ACE System for Pilot Attention Monitoring and Control

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Abstract:

In this report the problems of the reliability of pilots interaction with equipment inside the advanced plane cockpit are discussed. The main lines of the research concerning possibilities how to improve this reliability interactions are pointed out.

There are two main areas, which are proposed for investigation:

a) The reliability of pilot's reaction on various stimuli to which he/she has to face in the course of his/her flight operation.
b) The development of a warning system, which could decrease the danger of operation faults caused by non-satisfactory attention level of the pilot. For other transportation facilities similar warning systems for operator (driver) attention decrease are also being solved within the frame of other research projects.

As concerns the advanced plane cockpit, a set of special questions must be solved for its integration in the cockpit systems. In this report the expected necessary steps of respective research are proposed.

From all the factors involved in the human subject attention level the speed and correctness of pilot reaction is taken as one of most important. The dependence of these factors of pilot attention level on the kind, size and location of the to him/her incoming stimuli is proposed as first step for investigation. Introductory results concerning the dependence of probands reaction time on the kind and location of visual stimuli are presented. The correlations of these factors to the EEG of the pilot are used for a proposal of the on-board applicable detection and warning system preventing the eventual decrease of the pilot attention below the limit of reliable and safe control of plane.

Content:

1. Introduction

The pilot in his cockpit, especially in contemporary fast military planes, is exposed to extremely intensive influence of various signals, coming in increasing frequency not only from the plane environment, but also from the still large number of the cockpit instruments and also from the ground control. The pilot attention must be in the course of his/her flight continuously considerably very high. Each its decrease below certain standard can cause false operation and eventual failure of the plane mission or even the accident.

In spite of the fact the skilled pilots are intensively trained to be resistant against various disturbing influences, especially of the physical, physiological and psychical nature, they are still not enough protected against the effect of their attention decrease, which naturally appear in the course of their operation and which can be a very serious reason for lowering of the reliability of their interaction with plane control and communication units. Of course, even the high trained pilots when exposed to severe environmental condition, are more sensitive to fatigue from long operation service and their reactions on presented stimuli could be much less reliable.

The modeling of pilot activity inside his/her cockpit can be considered as a part of the general problem of human subject activity modeling.

Like in many other cases in this area, also here we are especially interested on problems, related to the reliability of pilot interaction with the advanced cockpit system and on the speed and correctness of his/her reaction to various stimuli, which are him/her presented in the course of the operation service.

Because of the contemporary fast development of the aircraft avionics, computer and information technologies and recently also of our deeper understanding to the brain functions, the pilot's activity is significantly transformed from the recent set of elementary flight control operations to much more sophisticated decision making activities the complexity of which is usually so high, that there is hard need of utilization various autonomic decision supporting subsystems. Of course, its support for pilot's decision must be arranged so that the final decision can be realized in real disposable time limit (often very short).

An overview of basic tasks solved by pilot in the course of flight is schematically shown (according to [10]) in Fig.1. Only some of the related tasks solves the pilot alone, he/she usually uses the help of several specialized auxiliary decision supporting subsystems.

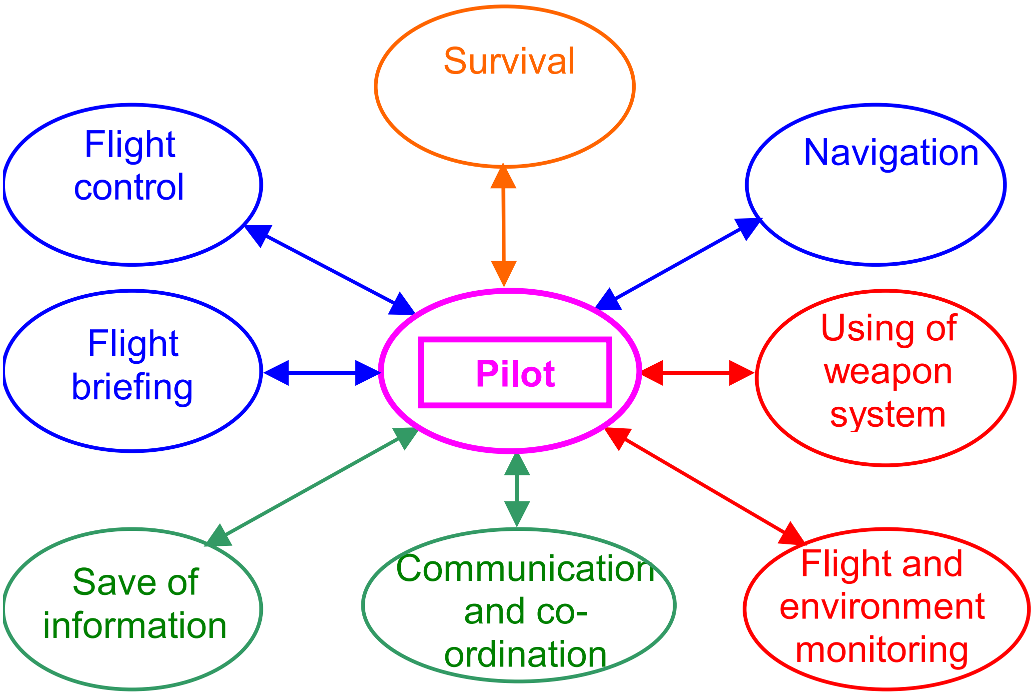


Fig.1: Basic tasks solved by pilot in the course of his/her flight operation

For the pilot the **pink** color is used here. He/she interacts with four basic kinds of cockpit systems:

a. The system for flight control and navigation – marked **blue** in Fig. 1,

b. The communication system, – marked **green** in Fig. 1,

c. The weapon and defense system, – marked **red** in Fig. 1,

d. The pilot survival system – marked **orange** in Fig. 1.

As concerns the contemporary flight control systems, they are default comprised by autopilot, power booster and control computer, they allow the pilot to feel free from routine operations and enable using of his/her ability especially for solving distinct flight situations. They also assure taking-over of the pilot’s activity in case of his/her operation failure.

As concerns the navigation, the intelligent computer and GPS based contemporary navigation systems save also a lot of formerly difficult and exhausting work of pilot's brain.

He/she can therefore use much larger part of his/her intellectual capacity and attention for operation with weapon systems, flight and environment monitoring, communication and co-ordination. However also in these cases take place the automatic support of intelligent on-board computer controlled systems, the activities of them are of course under final supervision of the pilot. Therefore the pilot can save a good part of his/her mental capacity and concentrate himself / herself on the solution of the higher intellectually tasks. Among these tasks are before all the activity of planning and of decision making on the kind of all these subsystem exploitation, which represent the tasks the solution of which requires very sophisticated knowledge control.

As concerns the systems supporting the pilots living conditions in the course of flight and also during eventual escape operation in the course of an accident, these usually function almost automatically, without significant possibility that the pilot can change their operation parameters by his/her will. However, their reliable operation needs the input of some values, which are measured (usually almost continuously) on the pilot and which characterize his/her physical and mental actual state. Among such values the measurement of pilots EEG signals is recommended to be included, because this opens the possibility to develop a warning system preventing the faults coming from the decrease of pilots vigilance and attention.

The problem of interaction reliability among all these artificial systems and human beings (pilots and also other system operators), though extremely important, is still not satisfactory solved, even the control of dominant part of complex and complicated systems (like the modern aircraft without any doubt is) is now realized by computers or at least with computer assistance. The human operator, in the case of this study the pilot, who has to interact with powerful, complicated and often also efficient artificial system (as aircraft control systems represent), is imposed to requirements on fast and correct reactions (the necessary reactions can be also quite complicated) on very variable actual situations and he/she is exposed to this for considerably long time of his/her service.

The resulting high load of pilot brain and nervous system results necessarily to subsequent decrease of his/her vigilance and to degradation of his/her attention.

There exists a <u>belief</u>, that in military battle planes, like fighters are e.g., the length of flight is in average not so long, that these effects of the fatigue from plane control could not be of special importance.

We feel this idea is a dangerous misconception, however.

The intensity of fatigue caused by the interaction with any artificial system can be expressed by the integral of the actual operator or user attention level realized by the particular operator in the course of time of his/her interaction with the respective system.

If the actual level of attention in certain time instant t_a is denoted as $L_{AT}(t_a)$, the fatigue exposition FE can be expressed as

$$FE = k_p k_o \int_{t_o}^{t_f} L_{AT}(t)\,dt \quad \text{……………………………………………………………..(1)},$$

where, k_p is the constant representing the individuality of the particular operator (pilot),

k_o is the constant representing the specific conditions of the particular plane and of its kind of actual operation,

t_o is the starting time of the operator (pilot) service,

t_f is the time of the end of his/her service.

The values of FE increase in the course of operation in principle, however this increase need not be of the monotonic character. In certain specific intervals of service time, the values of FE can temporary decrease, because the pilot under consideration could relax (see Fig. 2 e.g.).

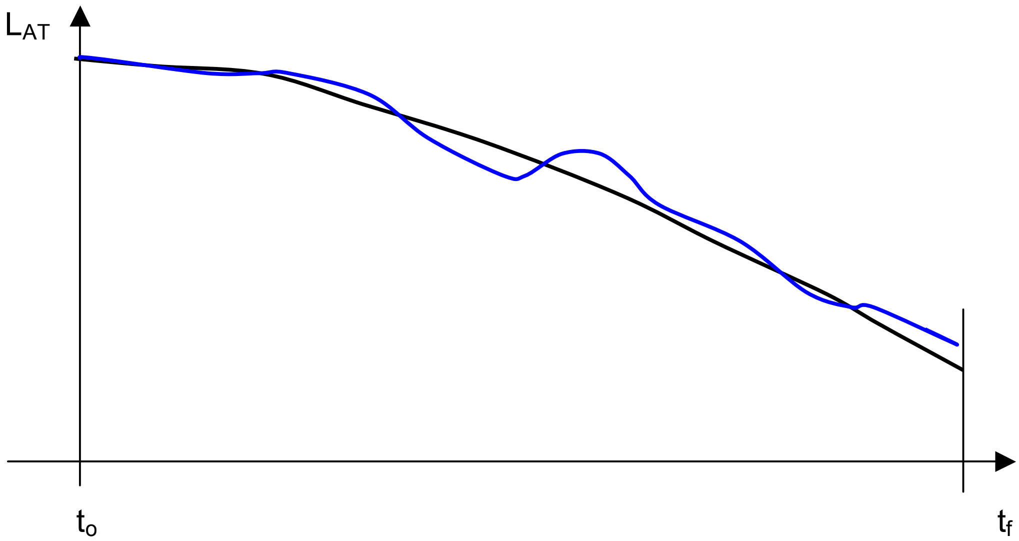


Fig. 2: Schematic course of system operator (pilot) level of attention L_{AT} in the course of his/her service. Black line: idealized monotonic decrease, blue line: decrease with temporary relaxations.

This means that the fatigue exposition FE is proportional to the integral of the level of attention, which the operator needs to realize in the course of his/her service.

The values of FE differ for each specific kind of flight operation and plane. Though their determination could be considerably laborious, their knowledge can be very useful for decision, if the particular pilot is able to operate well.

Each human subject has to his disposal certain maximal capacity FE_{max} of the FE, which he/she is able to utilize . This capacity is exhausted in the course of his/her service. The kind of exhausting can be quite different: considerably low required levels of L_{AT} in the course of long time, or much higher required levels of L_{AT} for short time interval (of course, the total disposable capacity of FE of particular person can be improved by intensive specialized training). The existence of individual FE_{max} limits causes that even in the case the length of service of pilots in certain military air activities could be considerably short, the pilots disposable FE_{max} capacity could be eventually exhausted considerably soon, if the requirements on his/her attention level are too high.

When operating with modern fast aircrafts, the pilots can considerably often face according to our knowledge to a such situation, in which they become to be near (or even over) the limits of their FE_{max} capacity.

Of course, the exhausting of the FE_{max} capacity is not monotonic in practice. In some instants much higher level of attention are necessary then in some others. If in these intervals of lower required values of L_{AT} the pilot attention can be lower than certain limit, he/she can really relax. However if the minimal level of necessary attention is not low enough, the result of such changes of realized levels of L_{AT} is worse, than in the case if the capacity FE_{max} is exhausted continuously. This concerns especially the cases, when the changes of required values of L_{AT} are large and sudden.

Unfortunately, our present knowledge on the dependences existing among all these factors is still not satisfactory and much more research has to be done, especially as concerns the distribution of FE_{max} capacity in the population and the efficiency of various methods for its improvement.

For further research on modelling of the pilot interaction with the systems of advanced cockpit and investigation of its reliability we expect to focus on the following two areas:

a) The reliability of pilot reaction on various stimuli to which he/she has to face in the course of his/her flight operation.

b) The development of a warning system, which could decrease the danger of operation faults caused by non-satisfactory attention level of the pilot. (For the other transportation facilities similar warning systems for operator (driver) attention decrease are also being solved in the range of other research projects.)

Both these goals are related. The knowledge in the direction a) is necessary for serious research in b).

As concerns the goal b) i.e. the development of some practical, on the board of modern advanced air-craft cockpit applicable tool for system operator and/or his/her supervisor in-time warning against the danger of his/her attention decrease below the limit of safe and reliable operation of the particular system, we have to answer to a considerably wide list of open questions.

These are related to both above mentioned main areas of investigation concerning the reliability of pilots interaction with advanced cockpit environment, i.e. the analysis of the reliability of pilots reaction on presented stimuli and the development of warning system against the decrease of pilots attention. In more detail we shall discuss this later on.

As concerns the goal a), i.e. the investigation of the reliability of pilot reaction, we focus before all to his/her reaction time RT and correctness P_{corr} of his/her reaction.

As the most important here the following questions have to be picked out:

a) Which are the typical maximal allowable values of reaction time RT for various system operations situations?
b) How do the typical values of RT depend on the kind, size, intensity, contrast, duration and location of the presented stimuli?
c) Which are the inter - dependences of RT and P_{corr}?
d) Which is the correlation among such values of RT and the most significant components of EEG signals projected in the surface of operator head?
e) How can we predict the expected development of these EEG components?
f) How we can improve the obtainable values of RT and P_{corr} for various plane operation situations and for various pilots?
g) Which will be the recommendable block structure of the respective warning system?

The present level of our knowledge does not allow the reliable answers on all these fundamental questions, however we expect that in reasonable time of few years of intensive international cooperation (namely by the use of knowledge reached in the range of the OECD Global Science Forum project “Neuroinformatics” and also in the range of the research projects No. ME 478 and VZ 210000024 of the Czech Ministry of Education being solved at the Czech Technical University, Prague, Faculty of Transportation Sciences) it will be possible to propose such on-board applicable equipments, which as an integral part of the advanced cockpit environment can help to the significant improvement of the operation reliability of interactions between the pilot and the plane.

In this report we try to contribute to the answering some of these questions from the presented list (namely the question b) and g)) and to outline the way to answer the others.

2. General role of interaction with human subject in artificial system operation

The unsatisfactory reliability of nearly all-artificial systems in use by man throughout the history represents one of the main problems of civilization. This is caused not by the low reliability and short lifetime of artificial systems themselves, but very often, due errors by human operators who deal with such systems. Recently, the technological progress of the reliability of artificial systems has greatly improved. Consequently the probability of technical faults in well - designed and well - manufactured artificial systems is now usually very limited. However, the probability of failure caused by misuse and faults in system operator activities increases rapidly.

The main reason for this un-favorable situation can be seen in increasing requirements on an operator’s ability, his/her level of continuous attention and the speed of his/her reactions.

Naturally, the losses caused by artificial system operation faults are proportional to their power, significance and value. In the case of many modern transportation systems (fast and large airplanes, fast trains, large ships, trucks), large power plants, important financial systems, security and defense systems, and also important systems for medical care, the losses caused by their malfunction could be catastrophic both in their character and consequences.

Therefore, besides the continuing interest in diminishing the probability of technical failures in any artificial system as much as possible (with respect to economically acceptable expenses), considerable interest has also been shown in recent years in the reliability of system operator activity. Many statistics demonstrate that the amount of human error represents a still larger proportion of all the expenses, which are required for the compensation of artificial system malfunctions.

The requirements on a human operator of an artificial system can be concentrated generally in the following main categories:

a) requirements on attention level and continuity,
b) requirements on the speed of operator reaction,
c) requirements on the correctness of operator decisions.

Within all three above-mentioned categories of the reliability of human operator - technical system interaction a correlation naturally exists.

A straightforward correlation exists between attention level and speed of reaction. Operators commanding a high level of attention usually also possess very fast reactions. On the other hand some cases can appear, when fast - almost impulsive - reaction is not accompanied by very high level of the operator’s concentration and attention. Some people can react fast also when their attention is distributed among very different objects (they have very fast reflexes).

In addition, a high level of attention in the majority of cases leads to a very high probability of correct decisions and vice versa - if somebody is not concentrating enough, there is a rather low probability that his/her decision will be correct.

On the other hand, in the case of very fast reactions accompanied by a very low level of a human operator’s attention, the probability of an incorrect decision can increase significantly. This is typical for a so-called surprise reaction, from which a transition to a panic reaction can sometimes be observed.

The relations among the three above-mentioned categories can be visualised in Fig. 3.

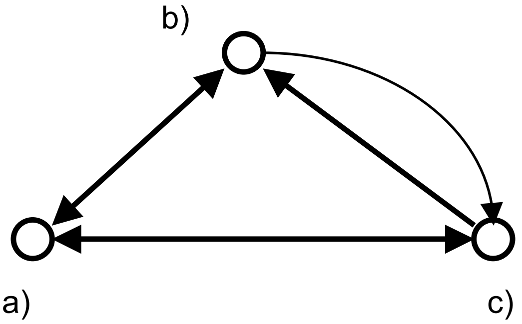


Fig.3: Symbolic representation of relations among the categories of requirements on human operator attention. Here a) represents the attention level L_{AT}, b) represents the reaction time RT and c) represents the correctness of reaction (expressed by the probability P_{corr} of correct response)

A drop in the attention level of a particular human operator can be caused by various external or internal reasons; some of them have a general character; the intensity of others depends significantly on the operator's individuality. Among the general conditions causing the decrease in attention is:

- Extreme length of a particular operator's service without breaks,
- Operator's physical and mental exhaustion,
- High psychical load,
- Monotonous scene, which the operator has to observe for a long time,
- Extreme temperature in which the operator has to serve (too high or too low),
- Extreme humidity in which the operator has to serve (too high or too low),
- Extreme air pressure,
- High long lasting vibrations,
- Air smell, dust density etc.

Matters leading the operator to concentrate on problems other than from his/her main service can likewise cause attention to drop.

All these circumstances in combination with a monotonous character of the operator's service, the scenes that are observed by him/her and his/her possible personal indisposition could lead to a significant attention decrease and even to the stage, called often as the micro-sleep.

3. Human vigilance, attention and micro-sleep

Before we start to discuss the problems of micro-sleep, we shall try to define this and related states of the human organism.

Looking at the available literature, we found that exist various descriptions of this phenomena concerning the fatigue states of human subject mental activity. These states can be characterised as such states of human organism, in which the eyes are closed and vigilance (and the attention also) approaches zero. This concerns various kinds of sleep and also the micro-sleep.

On the contrary, one can understand by micro-sleep also such a state of the organism, when its vigilance decreases below a certain limit.

There are several other conceptions of micro-sleep appearing to be between these two limits. Many people, especially in the field of neurology and psychology are still interested to improve the knowledge in this field.

In June 1998 at Kings College, London, M. Novák, V. Přenosil (Military Academy, Brno) and I. Valach (Air Force Research Institute, Prague) had the possibility to discuss the problem of what we have to understand by the term of micro-sleep with Prof. J. G. Taylor. The following statement has been considered as a reasonable pragmatic basis for further discussion and we use it till now as practical definition:

Micro-sleep is such a state of the human organism, in which the mental vigilance and attention of the human operator controlling some artificial system decreases for a maximum acceptable time below a certain limit, allowing safe and reliable control or use of certain artificial system. (D1)

The definition (D1) can be illustrated later on in Fig. 4.

However, firstly, we have to state what we mean by vigilance and what by attention, because these terms are often confused:

<u>Vigilance…</u>The state of the organism, in which all its mental functions can be realised and when all receptor signals are accepted and well processed.

<u>Attention…</u>The form of vigilance, when the dominant part of mental functions is concentrated on a <u>certain object</u>.

In a certain sense, attention can be considered as some special case of vigilance. In the state of vigilance, the human operator (pilot) can react adequately to the all received signals and the all presented stimuli. In the state of attention, he/she is usually concentrated on a certain group of received signals or stimuli, which are dominant for the function he/she has to accomplish . In the state of attention, the sensitivity of the operator can be lowered as concerns the other, non-dominant (secondary) signals.

Of course, the boundaries between vigilance and attention are usually quite blurred. Nevertheless, in the further discussion of the problems of micro-sleep, we shall deal with the term **"attention"** only, because this state seems to be more characteristic for human operators, who are able to interact well with artificial systems and control them properly.

Let us suppose that the level of a human operator's attention can be measured by the use of some scalar figure of merit L_{AT}, expressed by real numbers. The discussion of some possibilities of how to express L_{AT} and how to measure it will be mentioned here later on.

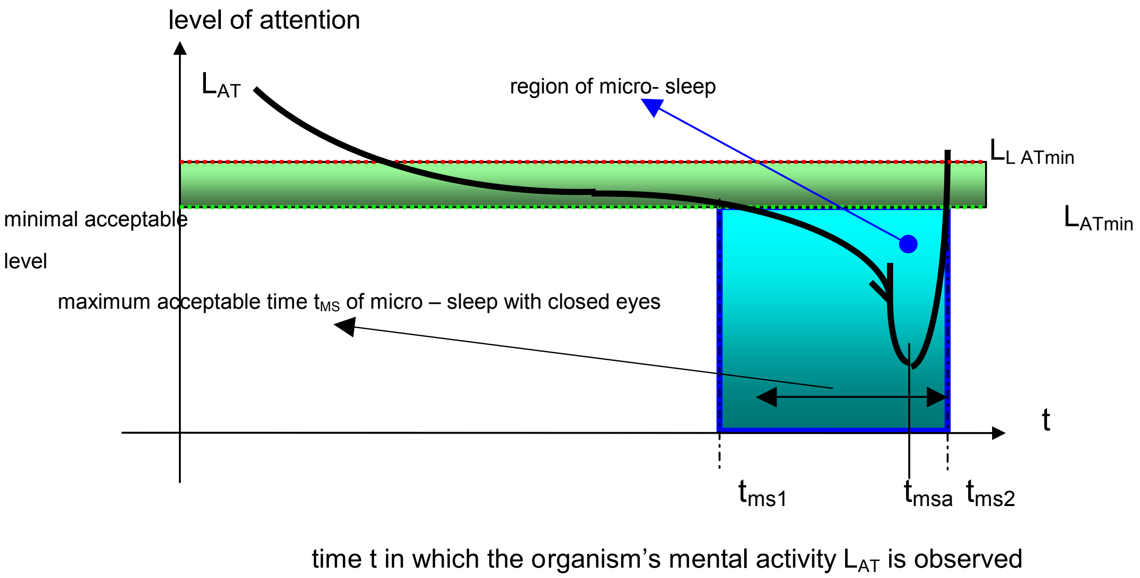


Fig. 4: To the definition (D1) of the phenomena of micro-sleep and its further discussion.

This discussion must be completed by at least the following considerations:

a) The minimal acceptable level L_{ATmin} of the human organism's mental attention L_{AT} depends significantly on the requirements which are necessary for a certain application of a human operator - artificial system interaction.

b) The micro-sleep can be further classified according to its general length in t and depth in L_{AT}.

As concerns the depth of the L_{AT} decrease, one can distinguish the following main stages:

Stage of the full vigilance (attention),

Stage of relaxation, where the level of L_{AT} is still satisfactory for basic control and safe use of the respective artificial system, however in which some remarkable increase of human subject reaction time and probability of false reaction appear.

Stage of somnolence, where the human subject is subsequently falling into asleep, looses at least a part of his/her ability for reliable and safe control (or even more – the use) of the respective artificial system.

Stage of micro-sleep or of sleep, in which this ability is lost almost totally.

These four main levels of human attention will be used for our analyses later on. As concerns the last mentioned stage, the micro-sleep, one can distinguish the two main classes of micro-sleep:

Micro-sleep with open eyes

Micro-sleep with closed eyes.

In Fig. 4 the region of limits in L_{AT} in which the first-mentioned class of micro-sleep appears is coloured by green; the region in which the second class dominates is marked blue. The intensity of grey shadows represents the depth of micro-sleep.

Micro-sleep with open eyes is usually a precursor of the micro-sleep with closed eyes and the boundaries between this stage and the stage of somnolence is quite fuzzy. At such a state of the organism some vigilance still exists, but the attention is considerably lowered and the reaction time is seriously prolonged. Also the probability of a correct and fast decision can decrease significantly.

This kind of micro-sleep (one can speak also about high somnolence) is very dangerous. In such a stage, which can also be considered as a light, or shallow micro-sleep, in which the particular operator is still able to partially control the respective system. After some time of further service, the light micro-sleep modifies usually into micro-sleep with closed eyes.

This second class of micro-sleep is usually partially similar to the regular REM phase of a real night sleep nevertheless it lasts for a much shorter time. The operator sleeping in micro-sleep with closed eyes cannot usually respond to any change of the system parameters, which she/he has to control.

The micro-sleep with open eyes can last for considerable long time and though the respective operator's attention in such a situation is still near the limit of the acceptable level (his actual attention level $L_{ATmin} \leq L_{AT} \leq L_{LATmin}$). The operator sleeping in such a form of micro-sleep has quite changed (lowered) other significant parameters (markers) of his attention and is practically unable to control any artificial system. Therefore, this can be quite dangerous.

The human operator's attention is represented in Fig. 4 by a scalar figure of merit $L_{AT.}$ However, for the actual representation of it, a large number N_{AT} of parameters x_i, i=1…N_{AT} has to be considered. For simplicity, in this report we shall deal with the reduced set of micro-sleep markers.

The set of all N_{AT} parameters x_i representing human operator attention forms a multidimensional space $\{X\}_{AT}$. The quality of a particular operator's attention can be represented by the position of the attention vector X_{AT} in this space. The methodical tools developed in the field of system parameter tolerances can be used (see [4] e.g.) for the necessary analyses of attention in the space $\{X\}_{AT}$. All the attention parameters depend on time t. In the course of t the vector X_{AT}(t) follows a certain N_{AT} dimensional trajectory Ψ_{AT}(t), which we shall call here the attention curve (for the idealised case of N_{AT} = 3 this is sketched in Fig. 5).

All the points of X_{AT}(t) corresponding to the acceptable quality of attention fill out some region of space $\{X\}_{AT}$, called the region of acceptable attention R_{AAT}. The shape and size of R_{AAT} depends on the operator's individuality and on the particular requirements on the operator - system interaction. Its investigation is quite complicated and laborious task.

Because the necessary analyses of R_{AAT} and Ψ_{AT}(t) in the multidimensional space $\{X\}_{AT}$ can be very difficult for $N_{AT} > 3$, we are interested to reduce this number as much as possible.

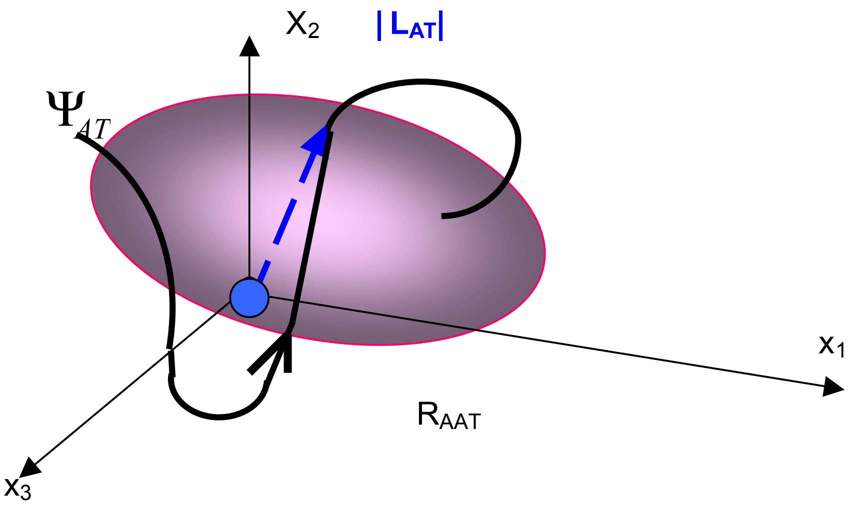


Fig. 5: Idealised example of the attention curve Ψ_{AT}(t) in the 3 dimensional space $\{X\}_{AT}$.

For the purpose of such a reduction the most significant parameters (markers) of a particular $\{X\}_{AT}$ are to be analysed and selected.

As maximal simplification some one-dimensional figure of merit of such a reduced set of attention markers can be used for representation of the attention level L_{AT}. In the case of the type shown in Fig. 5, for such a purpose, one can use the absolute value $|L_{AT}|$. For the purpose of this report a few of the most significant attention parameters of a general character will be picked out. A representative selection of them will, of course, require some more detailed investigation. This is expected for further stages of this project.

Preliminarily, we shall restrict ourselves here to the following main attention markers:

- The length of the micro – sleep $t_{MS} = t_{ms2} – t_{ms1}$.
- The speed s_r of reaction of the micro – dreaming human operator to an unexpected situation (this can be used in the case of light micro–sleep with open eyes).
- The widest angle α_{ob} in which the observed scene can be considered by an operator in the stage of somnolence (sleeping with open eyes).

- The probability P_{cr} of the correct response of a human operator to a certain unexpected situation.

All of these 4 markers, which we call the primary micro–sleep markers, may be measured by real values of t_{MS}, s_r, α_{ob} and $P_{cr.}$ They can be considered for the purpose of this report as satisfactory for the description of the particular micro– sleep. Of course, we are not able to draw a 4-dimensional graph corresponding to that sketched in Fig. 4.

The micro–sleeps of human operators, characterized in the respective 4-dimensional space $\{X\}_{AT}$ by points on the respective Ψ_{AT} trajectory, which are outside the corresponding region of acceptability R_{AAT} can cause very serious problems in practice. This concerns not only the dealing with transportation systems (piloting airplanes. driving of cars and trucks, controlling trains and navigating ships), but also the micro-sleeps of operators controlling traffic (especially dangerous can be micro–sleeps of air-controllers), power production plants, electric energy, gas, oil and water distribution systems. All such unexpected breaks in the human control of these systems can be extremely dangerous. A similar situation can arise when one considers the human control of medical, security and financial systems.

4. Natural limits of pilot attention

For practical purposes, we use some compact scalar figures of merit for expression of the attention level L_{AT}. The simplest possibility to express L_{AT} as inverse of the reaction time RT seems to be considerably rough. Therefore as reasonable compromise the product of RT and P_{cr} can be recommended. Nevertheless, that by the use of such simplification we can reduce the region of acceptable attention into one real number, the specification of limits of L_{AT} can be not easy task.

The minimal required values of L_{AT} vary considerably, not only with the kind of system under consideration and the kind of its control, but also with the individuality of the particular operator, his/her sex, age, actual physical and psychical conditions and also with environmental influences.

As far as it is known, there is not too much known till now about the evidently existing internal dependences among these factors.

In near future, much more investigation in this respect seems to be necessary. This concerns not only the top exposed cases of human-system interaction with artificial system, like are realized e.g. by fighter pilots, astronauts and express train drivers, but also many other situations, where the human lives and large economic values depends on safe and reliable man-system interaction.

Because direct methods can be only hardly used for investigations of these limits, the real testing of natural attention level limits has to be done mainly by simulation or "per analogiam".

One can simulate in the laboratory the situation of real system control and investigates the minimal values of $L_{AT\ min}$, which the tested person must realize for safe and reliable control. Though on contemporary simulators one can model the critical situations considerably easy, the investigation of $L_{AT\ min}$ is still laborious and time consuming, because the frequency of presenting the models of critical situations on which the proband (this term we shall use for the experimental person) has to react could not be too high. If yes, he/she can either adapt or on the other hand be stressed. Though many flight and other kinds of system operation control simulators exist, they are considerably rarely used for such determination of natural limits of operators attention.

The systematic investigation of these limits should be done of course not only from the point of view of the particular artificial system (type of plane, kind of operation etc.), but also with respect to the individual properties and abilities of the operator (pilot, driver).

Suppose, that we have to disposal at least some approximate knowledge, concerning the boundaries of the R_{AAT} under consideration. Of course, we have to take into account, that in many cases these boundaries are not sharp, but that they are of the more or less fuzzy nature. The problems of investigation of fuzzy regions of acceptability of attention cannot be however discussed in this report.

If we determine to each point inside the respective R_{AAT} the corresponding level of L_{AT}, we can calculate the value

$$L_Y = \int_{R_{AAT}} \Phi(X)\,dX \qquad \text{(2)}$$

Here $\Phi(X)$ is the density of probability of attention events realized by the particular system operator inside the region R_{AAT} in the course of his/her service.

The value L_Y can be considered as some figure of merit of the respective operator attention yield, which he/she is able to realize. The ratio

$$L_{av} = L_Y \,/ \int_{R_{AAT}} dX \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Though the expression for L_{av} is considerably complicated, especially as concerns its determination, it can be considered as the average probable attention level of particular operator and could be useful as very specific tool for classification of individual human subjects as concerns their ability to operate certain artificial system.

The laboratory investigation of attention level of many individual human subjects represents not only the basis for verification of efficiency and reliability of various analytical methods, but also allows to fill out the necessary data base on the behaviour of individual human subjects and their ability to ensure enough high level of attention during all his/her service and be resistive to psychical load.

The project of subsequent creation of such data-base (the Micro-Sleep Base, MSB) and of filling out its storing capacity by relevant data is prepared as a part of the international project “Global Neuroinformatic Net” of the Global Science Forum OECD.

5. Reaction time dependence on the presented video stimuli

On the base of the previous discussion one can take the reaction time RT as one of the most significant marker for the level of attention. The measurement of the values of RT seems to be very simple in principle, we just present in certain time instant $t_{s\,l}$ to the particular human subject some stimulus and measure the time delay, which appears between the instant of stimulus presentation and the human being response on it.

However, several quite serious questions appear if we would like to realize such measurement.

At first, we have to take into account that this is an invasive concept of measurement, in principle. By any artificial selected and presented stimulus we change, at least a little bit, the process of human subject attention decrease in the course of his/her service. By the necessary reaction on the particular stimulus the operator's attention is stimulated and just after some time it decreases to the normal procedure of decrease. This is characterized in Fig. 6.

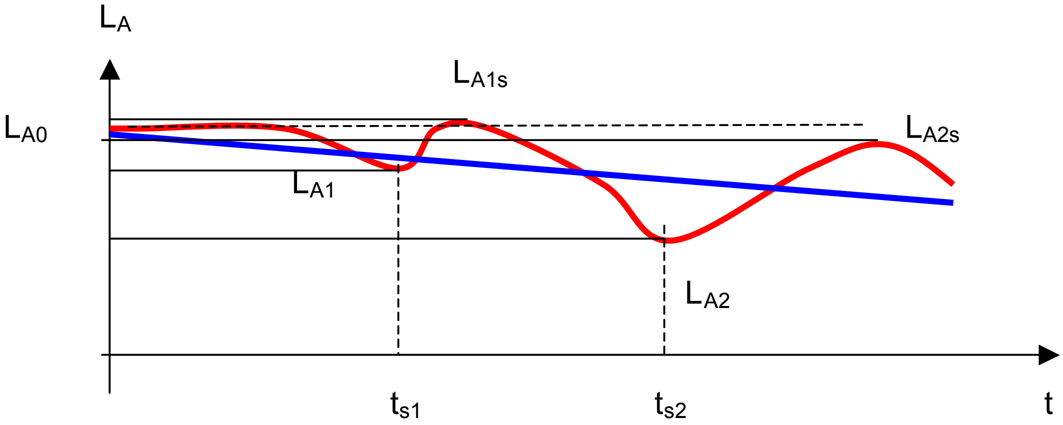


Fig. 6: The deformation (red curve) of the normal decrease of human subject attention (blue curve) by artificial stimuli presented in time instants t_{si}.

If the intervals between the two subsequent times $t_{s\,i}$ are not long enough, the attention decrease of the proband cannot stabilize and we receive deformed results. Of course the too long intervals between stimuli presentation leads to unacceptable time of measurement. According to our contemporary knowledge, the intervals in the range from 5 to 15 seconds seem to be recommendable.

Another problem consists in the choice of the kind, size and location of the stimuli.

The pilot in the real cockpit is exposed to various kinds of stimuli, which we call in this respect as natural stimuli. From the information point of view, these stimuli represent usually a short, (or very short) messages, and involving restricted amount of information.

In principle, they come from the following main domain of sources:

a) stimuli from plane environment (especially visual, sometime also vibration and noise),
b) stimuli from flight control system (visual, eventually audio),
c) stimuli from navigation system (visual, audio),
d) stimuli from strategic operation control (visual, audio),
e) stimuli from tactical operation control (visual, audio),
f) stimuli from pilot physical and psychical stage monitoring and warning system (visual, audio).

As concerns the environment, the visual stimuli dominate.

The information carried in visual stimuli is usually considerably higher, then that carried in audio stimuli.

Speaking about the visual stimuli, we have to take into account, that the nervous path for their detection and recognition in the brain is much more long and complicated than that, which serves for audio stimuli detection and recognition.

Therefore the values of RT on visual stimuli must be in principle higher than those for audio.

Another difference between the visual and audio stimuli recognition consists in the space sensitivity of the respective sensors. While the eye system can recognize the visual stimuli well only in certain part of observation field and those, which are near or behind its boundaries recognizes worse, or even does not recognizes anything, the space sensitivity to audio stimuli is much higher. Actually we hear the audio stimuli coming from any direction, even with some variation of the quality of recognition. As concerns the video stimuli, their source must be in our visual field. The fastest and most reliable the human subjects react on visual stimuli, located near the centre of their visual fields. If they appear near its periphery, the reliability of their recognition decreases. This fact is very important, because in many practical situations the visual stimuli appear near the periphery of visual field.

The existence of the dependence of human subject reaction time and the location of particular visual stimulus is known for a long time. However, the serious quantitative analysis of these dependences for most typical visual stimuli, coming into account for transport and especially for airplane cockpit situations is not at disposal.

Therefore we tried to investigate on small sample of young probands (group of our summer French students visitors) the dependence among the reaction time and the location, size, intensity, colour and time duration of various visual stimuli.

We have chosen the following:

Colour:	red,
	green,
	white,
	yellow,
	black,
Shape:	circles, of the diameter 5, 10 or 15 mm,
Location:	In the centre,
	In left upper corner,

In right upper corner,

In left lower corner,

In right lower corner of the visual field.

For the first series of measurements, the standard stationary background (light blue, simulating the blue sky) was chosen (see Fig. 7).

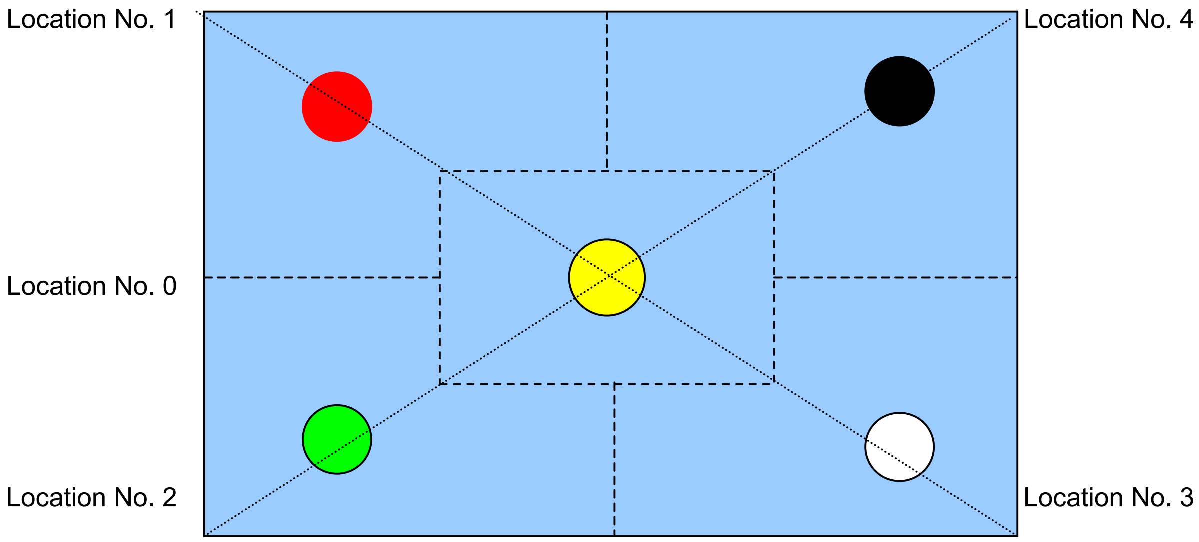


Fig. 7: Testing screen for visual stimuli, location and colour.

The circular stimuli were chosen with diameter 5, 10 and 15 mm. In the first series of experiments they all were of the standard brightness. The instants of stimulus appearance were chosen randomly in time intervals from 5 to 15 sec. The location and colour was changed also at random. The length of testing was chosen so, that at least 10 stimuli of each type were presented to the not tired proband during one session.

The the results are involved the report [11].

In the following tables a sample of these results is shown. Here the stimuli presented to the proband are identified by the following code:

location 0, 1, 2, 3, 4 accordint the Fig. 7,

color: red 1, green 2, white 3, yellow 4, black 5,

site of the stimulus: 5, 10, 15 (mm).

Proband No. 1:

Code of stimulus	0-0-5	0-0-10	0-0-15	0-1-5	0-1-10	0-1-15	0-2-5	0-2-10	0-2-15	0-3-5	0-3-10	0-3-15	0-4-5	0-4-10	0-4-15
Number of presented stimuli	12	8	10	8	9	8	14	16	8	10	13	11	13	10	10
RT [msec]	771	391	319	451	470	464	411	300	39	751	381	291	311	381	321
	300	310	416	440	360	499	461	481	368	310	411	346	581	301	31
	391	490	281	510	701	321	390	300	404	310	371	405	351	361	390
	441	341	300	592	451	390	841	321	462	361	441	310	391	320	511
	340	341	340	311	368	311	451	380	480	415	872	311	471	400	290
	303	472	430	421	330	320	391	427	281	927	303	380	424	462	361
	360	331	321	630	341	321	1083	439	320	301	331	290	458	321	381
	741	340	451	681	350	391	426	524	400	501	354	331	512	330	530
	341		276		381		461	600		571	320	360	291	340	661
	350		315				532	650		731	340	371	330	601	321
	560						350	728			360	411	331		
	611						391	280			421		390		
							441	311			621		411		
							961	350							
								481							
								571							
Average	459	377	345	505	417	377	542	446	344	518	425	346	404	382	380

Code of stimulus	1-0-5	1-0-10	1-0-15	1,1,5	1,1,10	1,1,15	1,2,5	1,2,10	1,2,15	1,3,5	1,3,10	1,3,15	1,4,5	1,4,10	1,4,15
Number of presented stimuli	8	9	10	12	12	11	15	11	17	13	11	14	12	11	9
RT [msec]	471	331	428	430	340	361	431	360	320	601	441	329	351	541	390
	391	481	537	381	381	364	430	430	352	401	371	388	321	420	422
	561	330	321	371	340	425	351	300	421	391	365	394	731	391	842
	407	571	300	451	361	280	571	291	507	480	410	401	371	391	320
	433	640	340	406	371	291	331	421	533	531	430	290	421	470	331
	638	490	360	642	391	350	410	360	593	431	577	341	676	387	371
	480	632	431	670	410	361	331	320	340	460	310	350	850	439	531
	691	458	421	350	411	371	357	369	351	450	351	461	893	449	777
		342	388	450	420	401	544	381	391	457	331	340	1062	467	431
			280	481	451	281	544	350	281	626	381	371	381	520	
				531	451	321	858	390	330	770	550	380	501	960	
				761	681		880		341	300		411	761		
							411		350	741		421			
							581		441			420			
							941		531						
									212						
									245						
Average	509	475	381	494	417	346	531	361	385	511	411	378	610	494	491

Code of stimulus	3-0-5	3-0-10	3-0-15	3,1,5	3,1,10	3,1,15	3,2,5	3,2,10	3,2,15	3,3,5	3,3,10	3,3,15	3,4,5	3,4,10	3,4,15
Number of presented stimuli	8	13	6	12	11	11	12	12	11	8	10	8	8	8	10
RT [msec]	781	441	375	681	741	310	371	852	320	831	471	280	421	440	308
	480	761	300	671	631	355	431	370	366	320	341	291	741	734	333
	481	311	330	410	321	527	651	415	432	461	390	341	1182	331	370
	621	311	335	280	490	301	310	546	341	344	308	350	741	371	528
	851	421	391	451	431	331	402	351	471	409	364	360	1152	390	440
	418	344	491	321	382	341	450	361	261	616	543	340	831	456	620
	511	397		781	504	361	466	391	280	450	685	360	866	462	671
	660	407		457	812	461	977	400	290	571	430	381	832	432	350
		561		481	340	290	311	430	300		461				480
		321		549	371	300	320	460	430		433				321
		360		400	501	300	391	560	511						
		361		440			540	911							
		431													
Average	600	417	370	494	502	352	468	504	364	500	443	338	846	452	442

Code of stimulus	4-0-5	4-0-10	4.0.2015	4,1,5	4,1,10	4,1,15	4,2,5	4,2,10	4,2,15	4,3,5	4,3,10	4,3,15	4,4,5	4,4,10	4,4,15
Number of presented stimuli	8	10	10	9	10	14	12	8	10	15	8	9	10	20	10
RT [msec]	360	270	311	431	320	1071	320	351	306	331	540	307	551	320	291
	551	540	405	1292	323	381	331	1092	366	411	441	389	420	280	416
	671	1160	310	397	481	281	561	351	260	390	351	432	401	990	321
	351	338	331	641	845	290	461	446	301	490	550	300	560	620	350
	901	349	290	1202	888	320	369	371	360	371	361	291	350	620	291
	571	364	321	511	280	350	403	401	381	291	425	310	381	321	330
	567	384	350	661	280	420	784	430	391	567	421	340	400	421	340
	564	409	511	871	320	931	321	430	340	320	440	321	481	340	298
		503	560	961	541	260	340		270	321		324	520	307	245
		851	601		433	321	521		341	351			571	375	320
						330	611			361				397	
						341	450			540				427	
						351				551				461	
						471				551				301	
										611				310	
														331	
														400	
														420	
														431	
														581	
Average	567	517	399	774	471	437	456	484	332	430	441	335	464	433	320

Fig. 8. Results obtained by proband No. 1.

The average results are summarized in the table on Fig. 9.

Code of stimulus	1-0-5	1-0-10	1-0-15	1,1,5	1,1,10	1,1,15	1,2,5	1,2,10	1,2,15	1,3,5	1,3,10	1,3,15	1,4,5	1,4,10	1,4,15
Number of presented stimuli	8	9	10	12	12	11	15	11	17	13	11	14	12	11	9
RT [msec]	471	331	428	430	340	361	431	360	320	601	441	329	351	541	390
	391	481	537	381	381	364	430	430	352	401	371	388	321	420	422
	561	330	321	371	340	425	351	300	421	391	365	394	731	391	842
	407	571	300	451	361	280	571	291	507	480	410	401	371	391	320
	433	640	340	406	371	291	331	421	533	531	430	290	421	470	331
	638	490	360	642	391	350	410	360	593	431	577	341	676	387	371
	480	632	431	670	410	361	331	320	340	460	310	350	850	439	531
	691	458	421	350	411	371	357	369	351	450	351	461	893	449	777
		342	388	450	420	401	544	381	391	457	331	340	1062	467	431
			280	481	451	281	544	350	281	626	381	371	381	520	
				531	451	321	858	390	330	770	550	380	501	960	
				761	681		880		341	300		411	761		
							411		350	741		421			
							581		441			420			
							941		531						
									212						
									245						
Average	509	475	381	494	417	346	531	361	385	511	411	378	610	494	491

Code of stimulus	2-0-5	2-0-10	2-0-15	2,1,5	2,1,10	2,1,15	2,2,5	2,2,10	2,2,15	2,3,5	2,3,10	2,3,15	2,4,5	2,4,10	2,4,15
Number of presented stimuli	10	14	11	11	11	10	9	11	11	9	15	11	9	9	7
RT [msec]	541	1192	333	421	391	477	441	331	465	380	441	312	601	562	313
	432	491	337	611	902	582	551	510	321	350	340	314	521	571	373
	522	441	364	321	296	832	390	521	390	401	841	321	390	306	576
	669	491	371	480	349	371	400	471	280	367	561	384	711	472	431
	841	390	418	321	356	381	347	297	290	404	311	393	479	475	761
	440	560	429	411	342	340	437	343	310	457	991	439	650	391	310
	770	360	447	681	542	432	470	359	311	465	520	506	450	401	380
	842	371	371	440	342	298	636	375	321	471	340	653	461	491	
	632	379	451	431	561	431	611	470	361	461	346	360	531	511	
	431	542	591	691	555	325		556	400		389	270			
		673	561	821	512			640	510		397	431			
		380									398				
		420									412				
		841									321				
											331				
Average	612	538	425	512	468	447	476	443	360	417	463	398	533	464	449

Code of stimulus	3-0-5	3-0-10	3-0-15	3,1,5	3,1,10	3,1,15	3,2,5	3,2,10	3,2,15	3,3,5	3,3,10	3,3,15	3,4,5	3,4,10	3,4,15
Number of presented stimuli	8	13	6	12	11	11	12	12	11	8	10	8	8	8	10
RT [msec]	781	441	375	681	741	310	371	852	320	831	471	280	421	440	308
	480	761	300	671	631	355	431	370	366	320	341	291	741	734	333
	481	311	330	410	321	527	651	415	432	461	390	341	1182	331	370
	621	311	335	280	490	301	310	546	341	344	308	350	741	371	528
	851	421	391	451	431	331	402	351	471	409	364	360	1152	390	440
	418	344	491	321	382	341	450	361	261	616	543	340	831	456	620
	511	397		781	504	361	466	391	280	450	685	360	866	462	671
	660	407		457	812	461	977	400	290	571	430	381	832	432	350
		561		481	340	290	311	430	300		461				480
		321		549	371	300	320	460	430		433				321
		360		400	501	300	391	560	511						
		361		440			540	911							
		431													
Average	600	417	370	494	502	352	468	504	364	500	443	338	846	452	442

Code of stimulus	4-0-5	4-0-10	4.0.2015	4,1,5	4,1,10	4,1,15	4,2,5	4,2,10	4,2,15	4,3,5	4,3,10	4,3,15	4,4,5	4,4,10	4,4,15
Number of presented stimuli	8	10	10	9	10	14	12	8	10	15	8	9	10	20	10
RT [msec]	360	270	311	431	320	1071	320	351	306	331	540	307	551	320	291
	551	540	405	1292	323	381	331	1092	366	411	441	389	420	280	416
	671	1160	310	397	481	281	561	351	260	390	351	432	401	990	321
	351	338	331	641	845	290	461	446	301	490	550	300	560	620	350
	901	349	290	1202	888	320	369	371	360	371	361	291	350	620	291
	571	364	321	511	280	350	403	401	381	291	425	310	381	321	330
	567	384	350	661	280	420	784	430	391	567	421	340	400	421	340
	564	409	511	871	320	931	321	430	340	320	440	321	481	340	298
		503	560	961	541	260	340		270	321		324	520	307	245
		851	601		433	321	521		341	351			571	375	320
						330	611			361				397	
						341	450			540				427	
						351				551				461	
						471				551				301	
										611				310	
														331	
														400	
														420	
														431	
														581	
Average	567	517	399	774	471	437	456	484	332	430	441	335	464	433	320

Proband No: 1				
Location 1	Upper left			
	Diameter	5 mm	10 mm	15 mm
Colour	Red	509	475	381
	Green	494	417	346
	Yellow	511	411	378
	White	531	361	385
	Black	610	494	491

Proband No: 1				
Location 4	Upper right			
	Diameter	5 mm	10 mm	15 mm
Colour	Red	567	517	399
	Green	774	471	437
	Yellow	456	484	332
	White	430	441	335
	Black	464	433	320

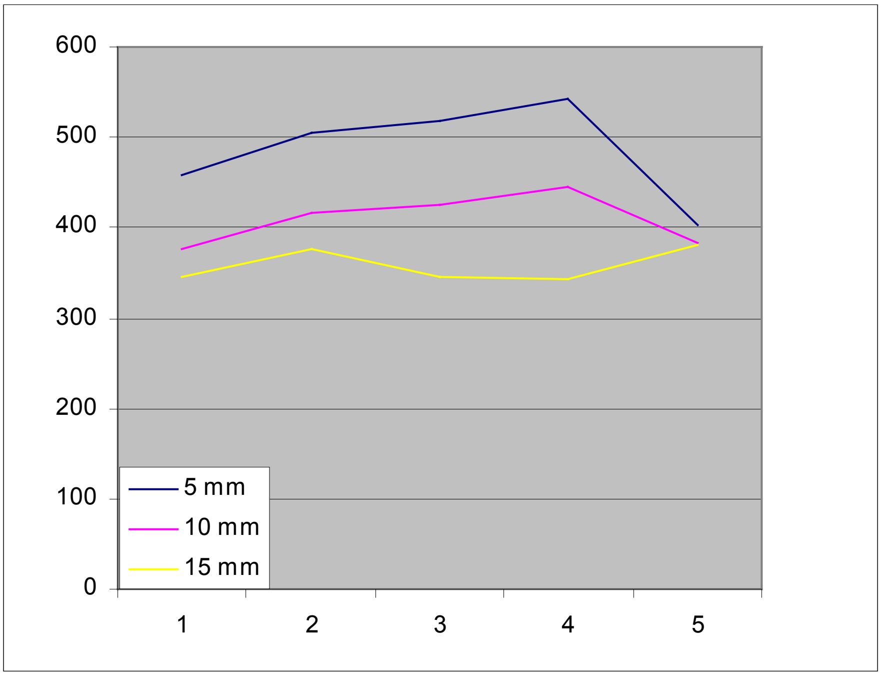
Proband No: 1				
Location 0	Center			
	Diameter	5 mm	10 mm	15 mm
Colour	Red	459	377	345
	Green	505	417	377
	Yellow	518	425	346
	White	542	446	344
	Black	404	382	380

Proband No: 1				
Location 2	Lower left			
	Diameter	5 mm	10 mm	15 mm
Colour	Red	612	538	425
	Green	512	468	447
	Yellow	417	463	398
	White	476	443	360
	Black	533	464	449

Proband No: 1				
Location 3	Lower right			
	Diameter	5 mm	10 mm	15 mm
Colour	Red	600	417	370
	Green	494	502	352
	Yellow	500	443	338
	White	468	504	364
	Black	846	452	442

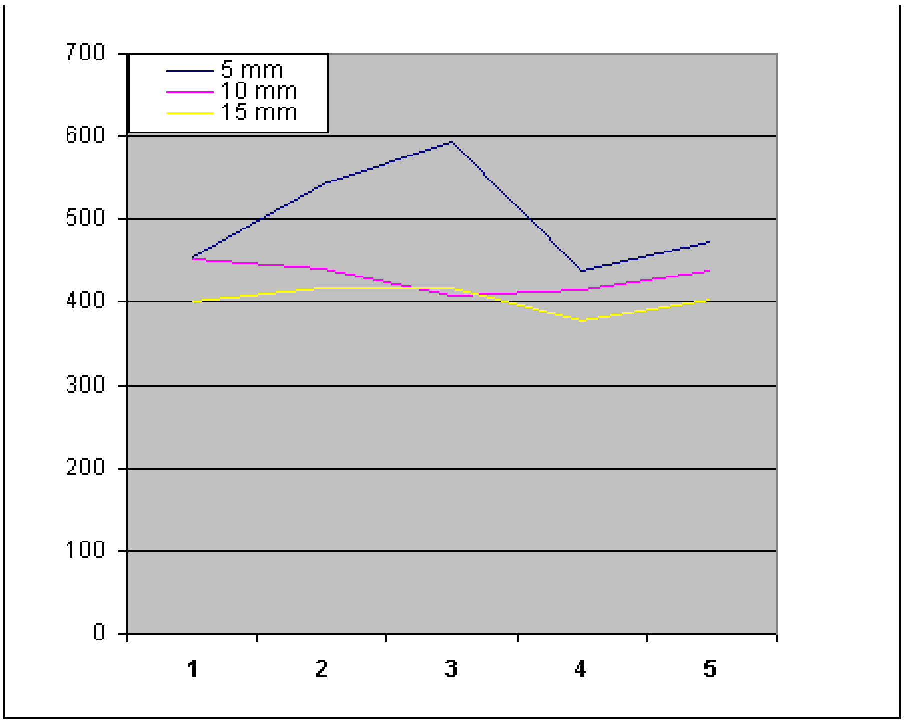
Fig. 9. Average values calculated on the base of measurement of the proband No. 1.

In the following 4 diagrams, some dependences found by this investigation are shown. These concern the influence of the stimulus size and color.



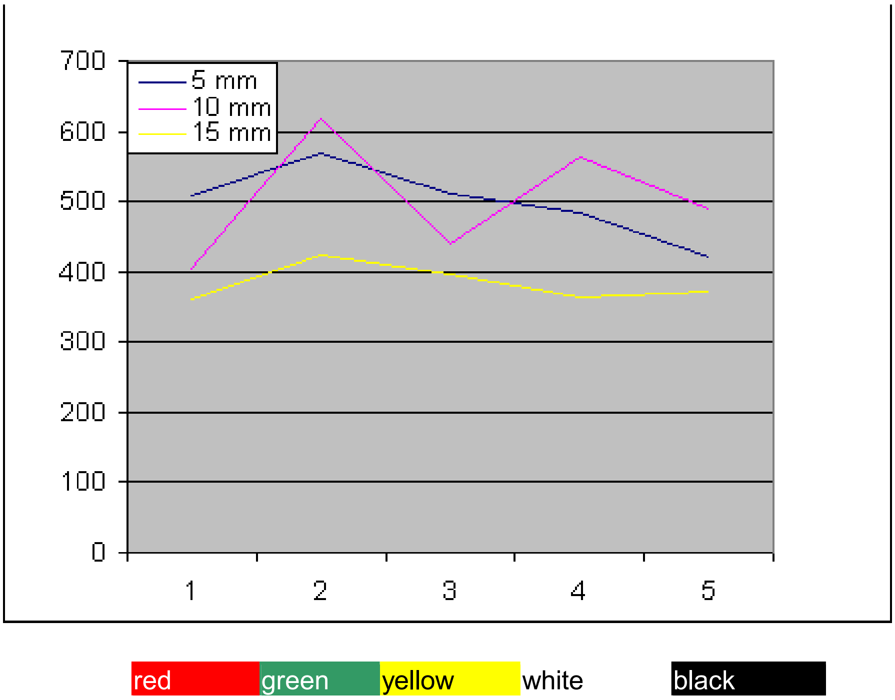
red green yellow white black

Proband No. 1

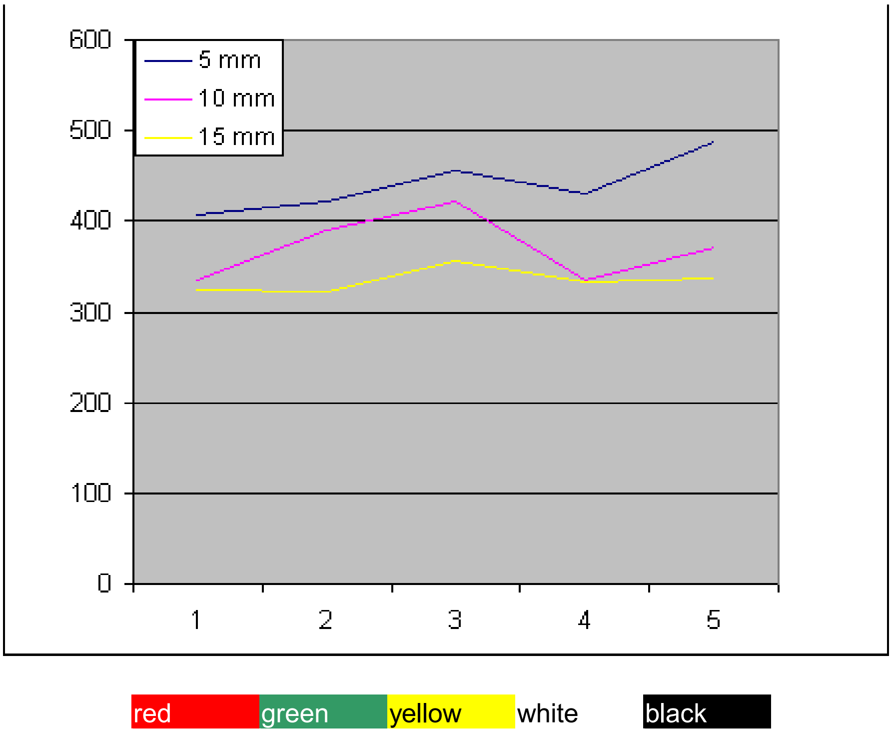


red green yellow white black

Proband No. 2



Proband No. 3



Proband No. 4

Fig. 10: Influences of stimulus size and color on reaction time of proband No. 1,2,3,4.

From these graphs one sees that the reaction time strongly increase with inverse of stimulus diameter. This seems to be evident, however there appeared also the dependence on stimulus color. For all probands, the shortest reaction time was obtained for red colored stimuli. For other colors the dependence varies. Evidently, much more probands need to be measured. This is expected to be done in the course of further investigatiotion in this serie of measurements.

For the second series of such measurements, the non-stationary background will be used. For this the video record of the view from the railroad engine, which the driver sees in his/her service, was chosen. This background was recorded on the line Prague – Česká Třebová, due the courtesy of the Czech Railways.

Next, the reaction time on the stimuli of various brightness will be tested, also.

Because of the considerably long lasting sessions, the probands could become tired during tests. For to be able to compensate this effect, we prepare the series of similar experiments in which we record the probands EEG in parallel with his/her reaction time.

From the previous research made on the micro-sleep problem in the range of the in the Introduction to this report mentioned projects there is known, that there exists certain dependence between some EEG pseudo-spectra components (namely alpha and delta) and probands reaction time. Because such dependence, the idealized example of which is shown in Fig. 11 is very individual, it must be investigated for each proband separate. Also the location of detecting electrodes on the probands head needs proper investigation, neverheless the area behind his/her ears seems be recommendable prom various practical reeasons.

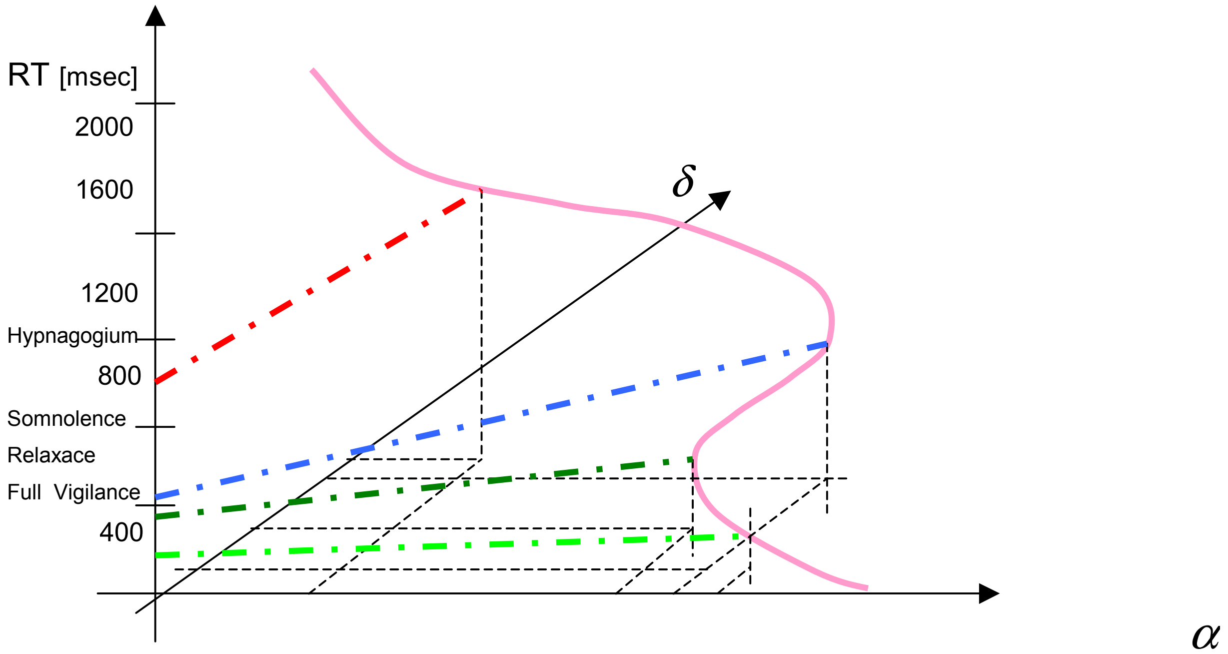


Fig. 11: Typical dependence among the proband´s reaction time RT and components α a δ of his/her EEG pseudo-spectra.

Similar investigation is proposed as concerns the typical audio stimuli, to which the pilot in cockpit is exposed. Here we expect the necessity to focus not only on stimuli represented by single tones, but mainly on stimuli of the vocal character. Evidently, here before all the simple commands and messages generated by the generator of artificial voice of sufficiently high quality have to be considered. As concerns this, probably the high quality artificial voice generators based on the method of so-called word synthesis could be advantageous (these were already developed for the application in advanced car cockpits).

6. Possibilities of EEG analysis for attention decrease warning

Let us suppose that the level of a human operator's attention can be measured by the use of some real figure of merit L_{AT}, expressed by real numbers. The discussion of some possibilities of how to express L_{AT} and how to measure it will be presented later on.

As it is schematically shown in Fig. 12, the level of attention L_{AT} decreases with the time, in which the human subject mental activity in the course of his/her interaction with the artificial system is observed. Here we can use the already here mentioned four basic stages, which we have already also used in Fig. 11:

a) Stage of the <u>vigilance (full attention)</u>, in which the respective subject is completely competent to control (or use) the system under consideration,

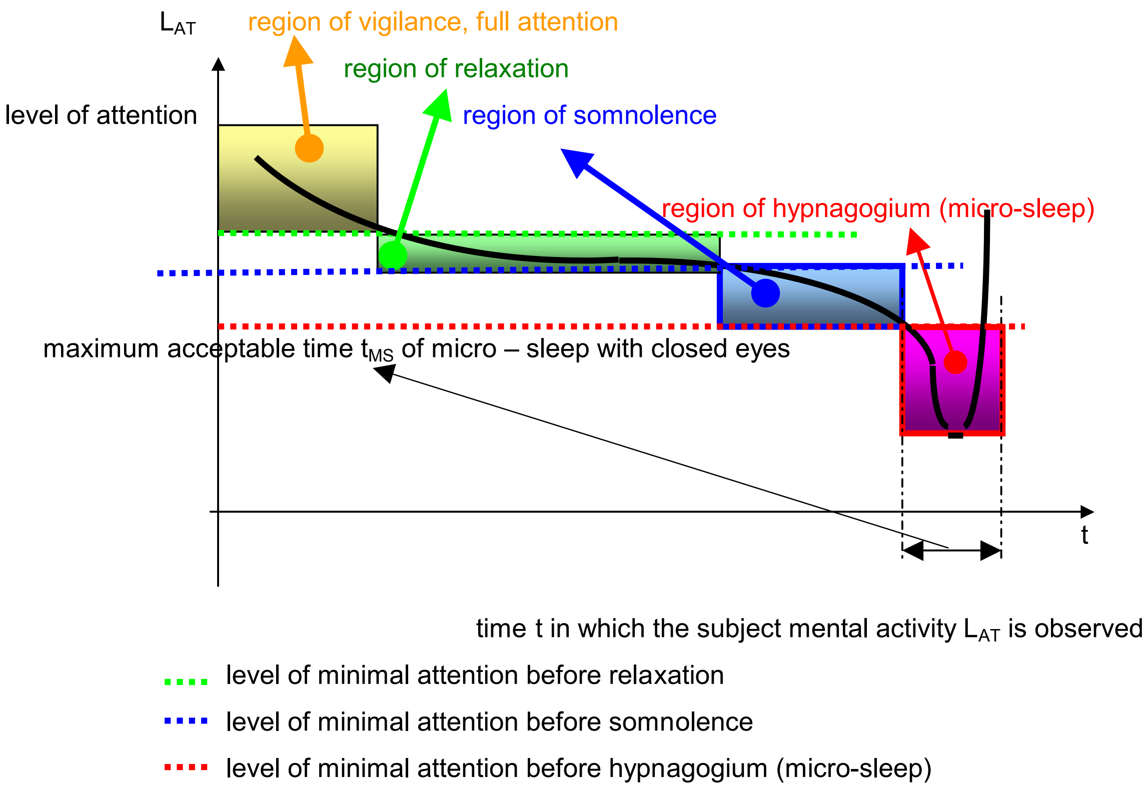


Fig. 12: The decrease of attention in the course of human subject activity.

b) Stage of <u>relaxation</u>, in which the respective subject is still competent to deal with the system under consideration, however where his/her attention decreases subsequently. This stage can last for considerably long time.

c) Stage of <u>somnolence</u>, in which the competence of the respective subject to interact with the system under consideration becomes to be restricted. This stage can last also considerably long, however in contrary to the previous one, here the real danger of the respective subject control faults exist.

d) Stage of <u>hypnagogium</u>, in which the respective subject fall into <u>micro-sleep</u>, at first with open eyes, however with very limited ability to control the system under consideration, later on into the micro-sleep with closed eyes, in which the respective subject competence to control the system is almost zero (some very skilled drivers -

namely the professional truck drivers - can also in this stage hold the vehicle in straight move, however they cannot adequate react to any road curvature or barrier on the road).

The Fig 12 is of course an in certain respect the improved version of the previous Fig. 4.

Micro-sleeps episodes can be of various lengths. For each kind of human subject interaction with artificial system some limits of maximum acceptable decrease of human subject attention and of micro-sleep lengths exist, over which the particular micro-sleep must be considered as dangerous. Of course in some cases micro-sleep can transform into the real REM sleep.

This discussion must evidently be completed by at least the following consideration:

a) The minimal acceptable level L_{ATmin} of the human organism's mental attention L_{AT} depends significantly on the requirements which are necessary for a certain application of a human operator - artificial system interaction.

b) The micro-sleep episodes can be classified according to their general length in t and according to the depths of the decrease in L_{AT} level (depth of micro-sleep).

The stages belonging to the class of micro-sleep with open eyes are usually as precursor of the micro-sleep with closed eyes. At such a state of organism certain level of its vigilance still exists, but his/her attention is considerably lowered and his/her reaction time RT is significantly prolonged. Also the probability of a correct and fast decision how to react to presented stimuli can decrease significantly.

This kind of micro-sleep is <u>very dangerous</u> though such a stage which can last for considerably long time period (though it can also be considered as a <u>light, or shallow micro-sleep</u>) in which a particular system <u>operator is still able to control the respective system, though often only partially and not enough reliable.</u>

After some time the light micro-sleep modifies usually <u>into real micro-sleep with closed eyes</u>. This second class of micro-sleep is usually partially similar to the regular REM phase of a real night sleep nevertheless it lasts for a much shorter time. The operator sleeping in micro-sleep with closed eyes cannot respond to any change of the system parameters, which he/she has to control.

The man control activity is here restricted to small set of basic control functions, which are produced automatically without any higher feedback from input receptors (see Fig. 13).

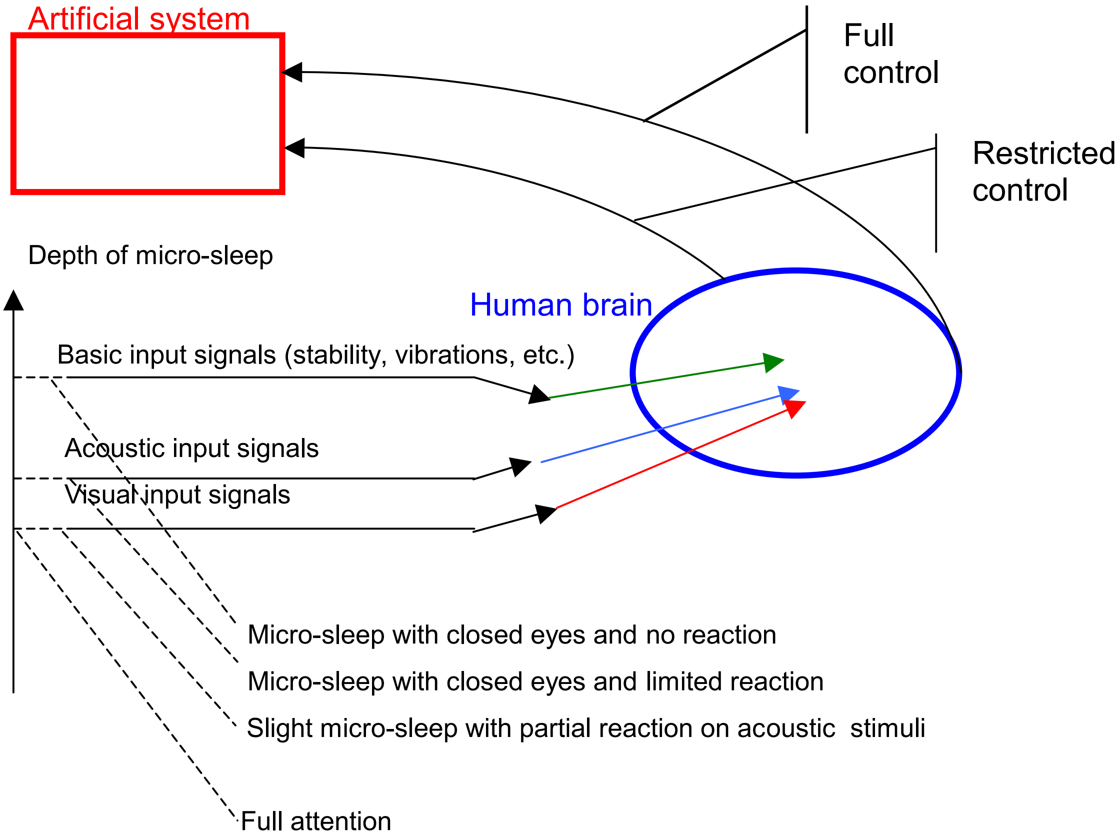


Fig. 13: Control functions in man-system interaction in the stay of micro-sleep.

We can suppose, that driver in the stage of micro-sleep with open eyes can react on some input signals of acoustic and visual character, though much slower and with higher possibility of wrong reaction, while when he falls in the mentioned light form of micro-sleep with closed eyes, he eventually can react on some basic input signals of mechanical character, like vibrations, acceleration and deceleration and position (stability), while in very deep micro-sleep with closed eyes he/she cannot react at all.

The micro-sleep with open eyes can last a considerable time and though the respective operator's attention in such a situation is still near the limit of the acceptable level (his actual $L_{ATmin} \leq L_{AT} \leq L_{LATmin}$). The operator sleeping in such a form of micro-sleep has quite changed (lowered) other significant parameters (markers) of his attention and therefore he/she is practically unable to control in full quality any artificial system. Therefore, this can be also quite dangerous.

The human operator's attention is represented in Fig. 12 by a scalar figure of merit L_{AT}. In maximal simplification, this can be considered as the inverse of reaction time RT.

When the human subject falls subsequently in the course of his/her artificial system operation in the stages of relaxation, somnolence and hypnagogium, his/her reaction times prolong significantly. While in full vigilance, the typical values of RT are about 200 ms, for the stage of somnolence RT in the range from 400ms to 500 ms appear and in the stage of hypnagogium the values of RT can exceed 800 ms. If the human subject load is prolonged more, it usually falls in real micro-sleep with closed eyes and his/her RT increases up to the time of awaking (this can be also several minutes). The values of RT in full vigilance below 200 ms are found exceptionally only.

The significance of danger caused by such prolongation of RT varies according the kind of human interaction with particular artificial system. Typically, for car drivers, the values of RT above 400 ms represent the distance about 15 m in speed of 100 km/s, which the vehicle runs without any specific control (braking, turn etc.) corresponding to the stimulus (signal) received by the drivers sensors (of course, to this distance one has to add the distance, caused by technical reasons, like braking time etc.).

Nevertheless, the representation of L_{AT} by RT is considerably easy and physically transparent, for the more accurate representation higher number N_{AT} of parameters x_i, $i=1 \ldots N_{AT}$ has to be considered. These parameters are called the micro-sleep markers. The exact analysis of them can be quite laborious. For simplicity, in this talk I prefer to deal with the reduced set of micro-sleep markers.

The endeavour of our investigations in the range of the above mentioned already existing projects is at present focused at the diagnosis of attention decrease and of the related reduction of the reaction speed to unexpected emerging situation. Such attention degradation can also result in real micro-sleep. Both these critical types of states of operator brain can be extremely dangerous and can result not only in huge material and financial damages, but also to losses of human life. Similar approach seems to be useful for solution of problems concerning the sophisticated plane cockpit environments.

For to be able to detect the attention decrease one has to select a set of significant parameters which can be used for identification the attention decrease and onset of micro-sleep.

Among such parameters belong:

the electro-magnetic activity of brain,

frequency of breath,

frequency of hearth beats,

eye movements,

skin resistance,

face grimaces etc.

All these parameters have their specific advantages and also disadvantages.

We have chosen the EEG activity as the dominant significant parameter, because this is probably the only one, from which the almost immediate and reliable information about the brain function can be analysed (similar information can be of course obtained from brain activity magnetic measurements, however their technical realization is much more difficult).

The analysis of EEG signals is in the focus of interest of many researchers, not only from the area of neurology, but also from electrical, control, signal engineering and mathematics

The EEG measurements can be realized in laboratory quite well and also we got considerably good results. The preliminary results with EEG measurements in the moving vehicle are also quite promising. There is a real hope that in not far future such EEG measurements in moving objects could be realized in real praxis.

After information mining from many EEG time-series recorded on several tenths of probands in our laboratory we can analyse the procedure of the respective operator vigilance decrease and attention degradation almost immediately and with quite acceptable reliability. As basis for such information mining we have used certain relations, which can be found among some components of EEG signal.

Here one has of course to take into account that the time-series representing the sampled EEG signal are in principle of the quasi-periodic and quasi-stationary character. Therefore, the classical concept of spectrum for such time-series does not exist. The standard methods for spectral analysis, based on Fourier decomposition into sum of periodical functions do not give accurate, representative and replicable results. Nevertheless, they are widely used for such purpose up to now, though their results are of limited use only. To avoid the eventual misunderstanding, we shall denote such results further on as pseudo-spectra. Nevertheless, careful analyses based on long-time experience of skilled human expert allow mine from the sets of data, obtained by such pseudo-spectral analyses a lot of useful information and knowledge [1)].

[1)] One serious drawback here is caused by the fact that in many neurological laboratories equipped by commercial EEG analysers no information about the kind of fast Fourier transformation used in the particular measuring set is at disposal, because this the manufacturer takes as his business secret. Therefore, the results of such analyses, obtained in various laboratories are not fully compatible. To avoid this source of uncertainty, we already have stimulated the development of fast pseudo-spectral analysis based on Gabor filtration, for which the respective polynomial filtration function of 50th order was designed. This we use now as standard analytical tool.

However, there is a good hope that another non-spectral approaches to quasi-periodical and quasi stationary time-series will lead to development of more accurate and sharp analytical tool than, which can be reached by pseudo-spectral methods.

Nevertheless, on the base of results derived up to now from up to now made analyses of above-mentioned pseudo-spectral measurements compared with the in time made measurements of the particular proband reaction-time RT and the correctness of his/her response on presented stimulus one can find the dependences like that already shown schematically in Fig. 11.

Of course such dependences are strongly individual for each investigated person and have be stored in specialized data-base, similar that we propose to develop in the range of the GSF OECD project “Neuroinformatics” and which we mention in the next chapter.

7. Proposal of the warning system

In the range of Global Science Forum OECD the world wide long lasting project “Neuroinformatics” was accepted July 2002. In the range of this project, on which many countries are taking part the international wide acceptable advanced data-base for storing and sophisticated analysis of many data generated by scientists working in the field of brain-science is proposed. This NeuroBase is in principal considered as open heterogeneous information system, consisting of many partial functional blocks, represented by regional, national and specialized databases. Such system needs for its proper function very reliable and safe exchange of information and data among interacting functional blocks. These exchanges will be realized by specialized interfaces in which the necessary translation functions will be performed. The functional coordination of the whole system (including all the functional blocks and interfaces), will be done by the international Neuro Portal.

Individual functional blocks of the NeuroBase will operate at various functional levels. Some parts of them will concern the internal operation of particular block, but others, which can be considered to be of the higher level, will be based on mutual cooperation of more blocks, dominantly through the Neuro Portal.

We have already propose to include in between the functional blocks of NeuroBase a specialized one, devoted to the data concerning the problem of human subject attention decrease and micro-sleeps (see [24,25]). This Micro Sleep Base (MSB) will have of the following main properties:

The MSB must be able at the top level of its activity to communicate with this international portal.

Of course, also the MSB represents in principal of the information subsystem of the heterogeneous nature. Therefore in its structure the internal portal must be included, which ensures the proper coordination and data and information exchange among all its partial functional blocks.

The Micro-Sleep Base itself represents therefore a considerably complicated heterogeneous specialized information system. It is proposed to consists of 6 specialized basic functional blocks, realizing their specific system functions. Among all of them mutual interactions exist. Because individual blocks operate with data and information expressed in their own alphabets and grammars, the translation of them in the proper form understandable for the particular partner block is necessary. These translations are realized by specific interfaces (not shown in the Fig. 12, where the basic structure of MSB is presented).

Because the MSB is proposed to act as a part of the international neuroinformatic base (NeuroBase), it must be able to communicate with the respective international NeuroBase portal (NI Portal). The proper interaction between MSB and NI Portal a specific interface ensures (also not shown in Fig. 14).

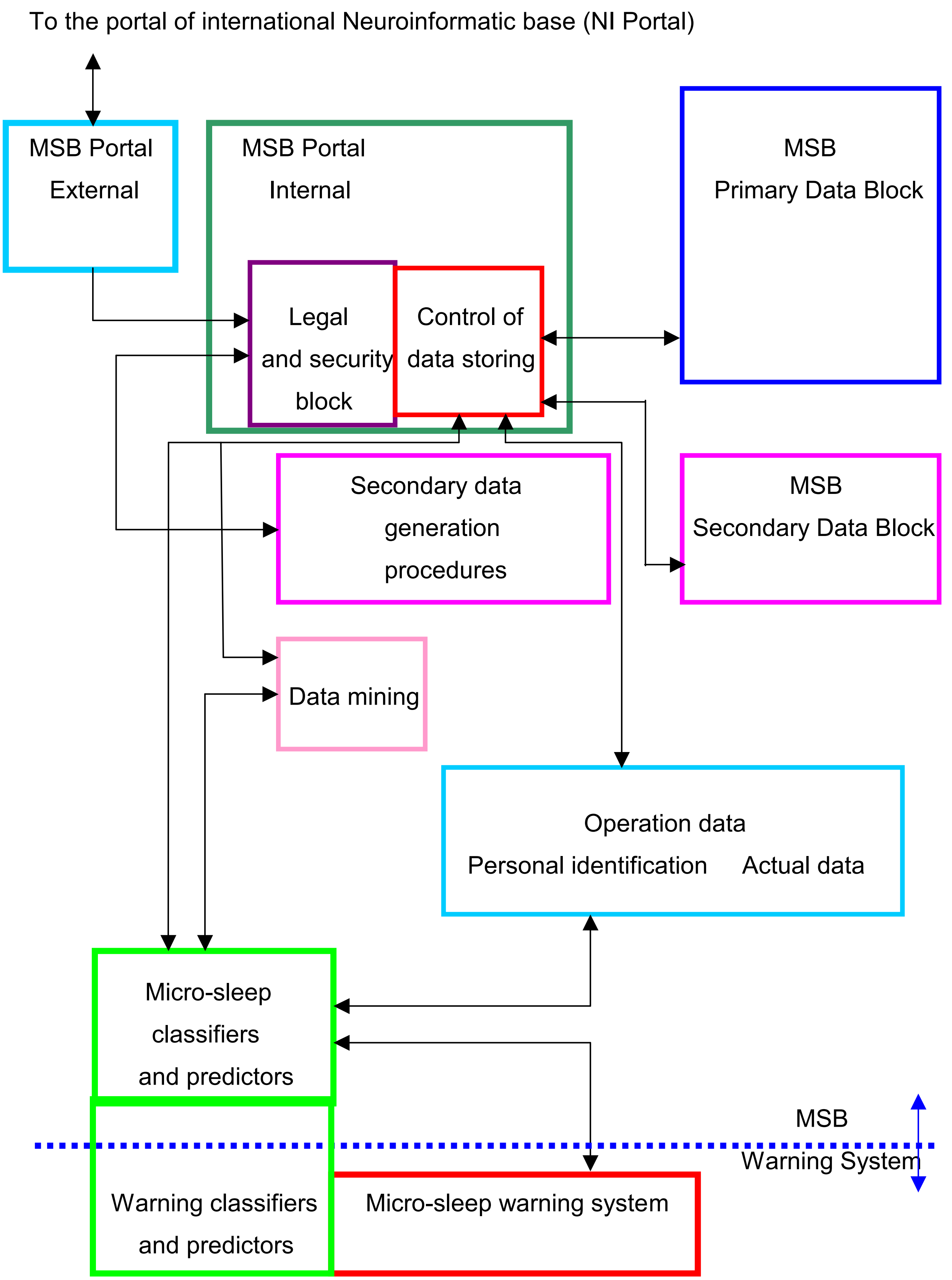


Fig. 14: The basic structure of MSB (interfaces are not presented). The blue dotted line represents the boundary between the MSB and the Micro-sleep Warning System. Some of the warning classifiers and predictors will be realized by special hardware.

The detail structure of the two MSB data blocks is shown in Fig. 15.

Primary Data Block

PD….Proband Data

PBEEG ….Proband Basic EEG Data

ADD…Attention Decrease Data

SD…Sleep Data

AM…Additional Markers:

- HV…Hand Vibrations
- EM…Eye Movements
- EMG…Electro Magnetic Data
- SR…Skin Resistance
- T…Temperature

Secondary Data Block

PSG…Pseudo Spectra – Gabor

PSFFT…Pseudo Spectra Fourier

PSM…Pseudo Spectra Maps

AI…Approximation Images

SSLC…State-space Life Curves

HE…Hill Equations

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Fig. 15: Proposal of the content of the MSB primary and secondary data blocks.

In the course of the research on detection, analysis, classification and prediction of human subject attention decrease and micro-sleep advent the extension of the content of the secondary data block is expected. This concerns especially the eventual results of new methods for analysis and classification of quasi-periodical and quasi-stationary time series.

The MSB will operate in several operation phases. The following are expected now, however more can be found to be useful after some practical experience.

At present expected operation phases of MSB:

a) Laboratory measurements
b) Data mining
c) Secondary data generation
d) Operation measuremets
e) Attention decrease and micro-sleep classification and prediction
f) Warning.

The control of all the MSB activities will be done in the MSB portal. It consists of two parts:

The External MSB Portal and

The Internal MSB Portal.

The role of the External MSB Portal was already mentioned in section 2 of this report. Its development is realized under the supervision of the OECG GSF Workgroup "Neuroinformatics" and is not in the focus of interest of this report. However, the necessary interface on the side of MSB must follow the respective NeuroBase standards, after they will be finished. Because the development of MSB will be done almost in parallel with the works on NeuroBase Portal, the respective interface between the External and Internal parts of MSB Portal needs to be constructed flexible.

All the internal supervision of the MSB function will be realized through the Internal MSB Portal (shown schematically in the left upper corner of Fig.14). It interacts straight with the block for legal and security activities, in which the approbation of the rights to exploit the MSB from other users will be realized. This block interacts straight with the block for data storing control.

The functions of Internal MSB Portal will be verified on special server of the computer network of LSR, Department of Control Engineering and Telematics, Faculty of Transportation Sciences, CTU Prague.

The basic structure of this block is shown in the upper patr of Fig.15. Its hardware basis is now the server OLAF of the computer network of LSR. The respective supervision software is written in JAVA. In this block the measured data are stored, namely:

- the Proband Data (PD), which involves the necessary characteristic of the respective proband (his/her name, sex, age, address, profession, basic medical anamnesis) – these data are of the alpha-numerical type,
- the data concerning the measurement of his/her EEG signals – Proband Basic EEG Data (PBEEG). Such data represent the group of time series (measured at present with sampling rate 128 samples per second), corresponding to certain specified placement of measuring electrodes on the probands head surface. The location of electrodes is done according to the international standard "10-20" (see Fig. 16). Various number of electrodes will be used for different probands, however certain minimal pattern of their location, shown in Fig. 17, is proposed to be used in any case as standard.

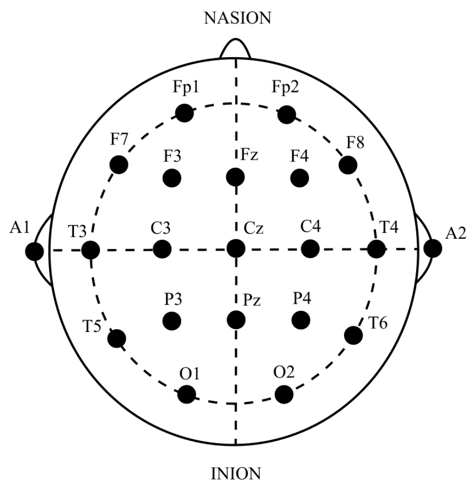

Fig. 16: International standard "10-20" for EEG electrode location on the surface of probands head.

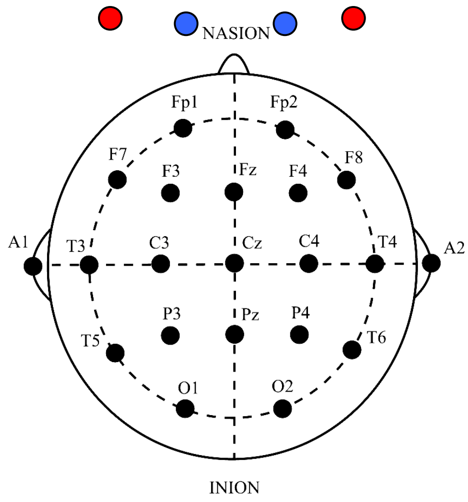

Fig. 17: Minimal recommended location of EEG electrodes on the surface of probands head (red spot – primary recommendation, blue spot – alternative recommendation).

The length of the stored time-series differs upon the actual condition of the particular measuring experiment, however at least 20 minutes is recommended. In the course of measurement the proband observes the screen on which the record of actual system control scene is projected (the view, which the car driver or rail-road driver sees from cock-pit, etc.). These records are recommended to be standardized for all the laboratories, participating on the MSB project.

- For the purpose of micro-sleep classification and prediction, additional data concerning the decrease of probands vigilance and attention in the course of measuring experiment are recorded. These data are stored in the Attention Decrease Data base (ADD).

For representation of vigilance and attention level the probands reaction time RT on suddenly appearing random stimulus is measured and stored, coordinated with the respective EEG signals.

For the purpose of the detection of probands reaction instant the simple manual bi-positional (or eventually multi-positional) handle is recommended. Each position of this handle corresponds to correct reaction on certain stimulus. As standard, the right hand control of this handle is preferred. The records of probands, operating preferably with left hand must be stored in separate part of this data-base.

Besides the length of reaction time RT also the correctness of the probands reaction is recorded and statistically evaluated.

- Similar character as PBEEG has the basis of so called Sleep Data (SD), where the records of time-series of EEG signals during the whole period of his/her night sleep is stored. Of course, here the RT is not investigated.
- Because besides the EEG signals also some other kinds of human subject signals are important for estimation of particular proband vigilance and attention level, also several Additional Markers (AM) are recommended to be measured and stored, namely:

Hand Vibrations (HV),
Eye Movements (EM),
Electro Magnetic Data (EMG),
Skin Resistance (SR),
Temperature (T).

The recommendation for the measurement and storing of these kinds of primary data will be formulated in separate reports.

In the secondary data bank of MSB are stored the data derived from the primary data by the use of some of the mathematical procedures, involved in the respective block of MSB. Evidently, not all these procedures are applicable for any kind of primary data. Besides the procedures of statistical nature, almost all other are focused on the EEG (or eventually EMG) signals.

Because the main part of the primary data consists of time-series, representing the EEG (or eventually also EMG signals), the mathematical procedures generating the secondary data are focused on their processing before all. However, these time-series are of the quasi-periodical and quasi-stationary nature. This causes, that the conventional methods and tools for spectral analysis, based on certain modification of Fourier transform can be applied here only incorrectly.

Therefore, dealing with results of such analyses, one has to speak about pseudo-spectra instead of spectra.

Nevertheless, almost all up to now known analyses were made on the base of this approach. The respective pseudo-spectra are stored in a special part of the secondary data-block of MSB (Pseudo Spectra Fourier – PSFFT). The considerably good results obtained by several authors can be explained by their high knowledge, intuition and long experience and skill in EEG time-series analysis.

From the pseudo-spectral lines the maps of their distribution on the probands head surface can be derived (Pseudo Spectra Maps, PSM).

For to prevent the problems arising from the low comparability of the results obtained by various modifications of Fourier transform, a special type of Gabor filtration (mentioned already in footnote [1)]) was developed. This is recommended to use as a standard one. The respective pseudo-spectra obtained by the use of this method are stored in special part of the secondary data block of MSB.

Because of the problems with the spectral analysis of quasi-periodical and quasi stationary time-series, several other approaches how to find the set of representative significant parameters (markers), characterizing with satisfactory accuracy the specific kind of such time-series corresponding to the proband particular stage and his/her level of ability to control or use respective artificial system needs to be developed. The research in this respect is in its beginning. Among the promising approaches the use of approximation of selected parts of these time-series and the investigation of the pole-zero location of the respective Z-transform images (Approximation Images, AI), the investigation of the shape of state-space life curves (SSLC) and the investigation of the coefficients of the Hill´s differential equations (Hill´s equations, HE) are to be mentioned.

In the various data, stored in MSB various information and knowledge will be involved, concerning the hidden interrelations especially. For the purpose of the necessary mining of the knowledge, a set of respective data-mining methods will be involved in the special block of MSB. Among them the approaches and tools on the base of the GUHA (General Unary Hypotheses Automaton) methodology is to be mentioned before all.

The interaction between the MSB and the warning system, which will realize the eventual generation of the information, that the particular system operator (pilot, driver, dispatcher etc.) is on the way to loose his/her ability of safe and reliable control of the respective system is presented in Fig. 14 by the blue dotted line.

Actually, this system can be considered as the extension of MSB useful for practical applications. In the case, that MSB is used for research purpose the activity of warning system is not necessary, of course.

<u>The first part of this system</u> involves the warning classifiers and predictors, Same of them can be realized by the use of micro-sleep classifiers and predictors, involved in the respective block of MSB. For mobile applications, some of these warning classifiers and predictors can be realized by special hardware.

The second part of warning system consists of the micro-sleep warning devices, realizing the transmission of suitable warning signal either to the system operator, or to system operation supervisor or to both. As concerns the signals for operator warning, the acoustic signals in the form of artificial voice are preferred (the intensity and aggressive tuning of this voice warning can be subsequently graduated).

The detail structure of the warning system itself will be proposed in special research report.

8. Expected steps for further research

For the purpose of the ACE research we propose the following further steps (work-packages):

a. WP 1: The further investigation of the reaction time on visual and audio stimuli.

Here before all the presented preliminary investigation on various kinds of visual stimuli has to be extended as concerns the influence of moving background simulating the real scene observed by particular system operator, and also various brightness of he stimuli has to be taken into account. As concerns the audio stimuli, the reaction time on selected set of word commands and messages has to be investigated. In all these investigations the probability of correct response needs to be taken into account. All these measurements have to be made on satisfactory large set of probands (probably several tenths), selected from adult, healthy people, which could be eventually candidates for pilots. The eventual effect of probands fatigue appearing necessarily during the measurement session is expected be compensated by the use of the parallel EEG measurement and respective correction of measured values.

The preliminary estimation of the man capacity necessary for solution of the WP 1 is 12 months for the period September 2002 till June 2003.

b. WP 2: The investigation of the visibility angle α_{ob} for various visual stimuli

Here the dependences of the reaction time and the probability of correct response on the horizontal deviation of appearing visual stimulus from the center of the observation field and on other stimulus characteristic parameters (like its duration, brightness, color, size etc.) will be investigated.

The preliminary estimation of the man capacity necessary for solution of the WP 2 is 18 months for the period September 2002 till December 2003.

c) WP 3: The testing of the correlation among the reaction time, probability of correct response, visibility angle and the most significant components of EEG pseudo-spectra for selected group of probands and storing of the relevant data in MSB.

The preliminary estimation of the man capacity necessary for solution of the WP 3 is 48 months for the period September 2002 till December 2004.

c. WP 4: Development of the functional sample of the micro-sleep warning system for the use inside the ACE system.

The preliminary estimation of the man capacity necessary for solution of the WP 4 is 36 months for the period January 2003 till December 2004.

9. Conclusion

The results presented in this report are mainly of the preliminary character. However, they open the way for further research and allow to say, that in principle, the nesessary methodical tools for to reach the goals formulated in the mettioned workpackages are at disposal.

Of course, much more measurements and tests on larger groups of probands will be necessary. The finding of representative probands is considerably complicated task, especially if they have to simulate the sample of the eventual crew of proposed advanced plane cockpits. In this respect the tihgter cooperation with the parthers from air-force will be necessary.

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