Improving simulation training: anesthetists vs nuclear reactor pilots

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Abstract
For many years, stress has been shown by researchers to be both a source of performance and a source of cognitive disorders. Studies have shown how to measure some of those parameters identified to be closely associated with the occupational stressed state of subjects, involving heavy medical facilities requiring specific devices and specific software for analysis. We have here elaborated a simple protocol requiring basic metrology and simple straight data analysis, qualified through specifics tests and showing a Yerkes & Dodson (1908) relationship between stress and performance. Application for reactor pilots and anesthetists training sessions on simulator has led to identify cognitive disorder zone during training and suggestions have been made for improvement.

1. Introduction

For many years, stress has been shown by researchers to be both a source of performance and a source of cognitive disorders. Getting information about the kind of influence of stress in a work activity has appeared very useful to be able to work mainly under the positive influence of stress. For this aim, qualitative considerations help, but the best is to maintain quantitative approach because of the objectivity. Many works have been done in order to make the link between stress and physiological parameters in a quantitative approach, and studies have shown how to measure some of those parameters identified to be closely associated with the stressed state of subjects. Nowadays, some medical facilities are available to do such investigations, which require specific devices, metrologies, and then demand specific software for analysis (see section 2). At each step, specialists are necessary. But for some industrial contexts, such a complicated organization cannot be applied, for a matter of time and money, while it would be of great interest to have better knowledge in specifics cases: classic training session, training on simulator, evaluation, crisis management…

Here we are involved in the elaboration of a simple protocol, requiring basic metrology and simple straight data analysis, to be used on training simulators (we shall propose the comparison of anesthetist and nuclear reactor pilot cases) by the trainers who are not necessarily experts in medical researches. We are interested in performance analyzed versus stress estimation. Different relationships between the occupational stress and the performance have already been obtained by others (for example see the review of Staal, 2004; and also the work of Broadhurst, 1957; Hancock et al., 2002). The final aim is to appreciate whether trained people are in a cognitive disorder zone or not.

2. Materials and Methods

This study deals with a specific kind of mental stress, the short term occupational stress, versus performance of workers. On the contrary of sophisticated metrologies and elaborated software which need, thereafter, a careful data examination to be sure of the conclusions (Montano et al., 2009; Rohleder et al., 2009; Schubert et al. 2009; Bailon et al., 2010), we aim at a simple solution based on heart rate. Preliminary tests have shown that relevant parameters (measured using a Polar FS2c) would be, for this kind of stress, the mean heart frequency (HR_{mean}) and maximum heart frequency (HR_{max}) as shown before by others (see for example Schubert et al., 2009). The following graph (Fig. 1) shows how the heart rate changes with the different steps of the test: for each question identified, the person starts to read, the person reads, thinks, begins to write, writes and thinks, turns the page and starts to read …

The heart rate always reaches the highest value in the initial stage of dealing with the question, either while reading, or when beginning to write. Then, during the treatment, heart rate decreases, and increases again if the subject hesitates (case of "stop writing" for example).

The record lets us think that, to have pertinent heart parameters concerning stress, we must be interested at least by a mean value and a max value.

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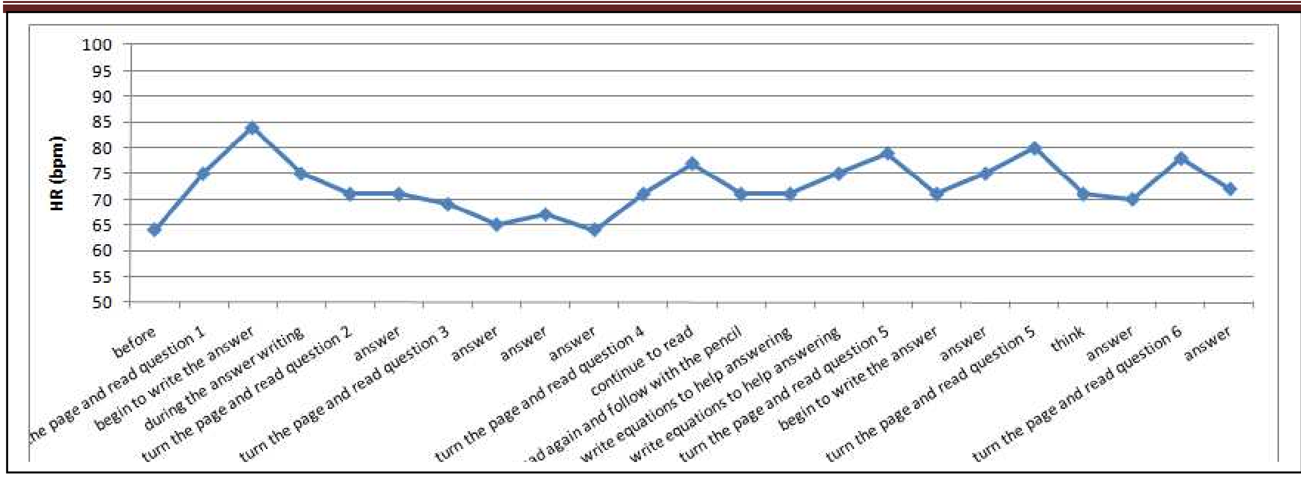

Fig. 1. HR changes during the Stress-test according to the actions done by the subject.

2.1.The Stress-test

A Stress-test made up of 12 questions has been first used to qualify the protocol and devices. It has been taken by French subjects (*N*=18; 50% male) healthy, same kind of academic background, about 25-35 yo, in two different conditions: No Stress and Stress Conditions. These two expressions are used to differentiate the test conditions, knowing that the first one refers to stressless conditions compared to the second one in which stress factors have been reinforced on purpose. For example, one of the stressful factors included in the Stress Conditions while not used in the No Stress Conditions of the Stress-test is the clepsydra. The clepsydra was said to bound the activity time length (Fig. 2) in a very specific manner; it was specially developed for the purpose. The clepsydra presented three holes in the upper part of its bottom receptacle and the subject was told to be expected to finish the task before the water would flow out of the holes on his/her desk, as the experiment was conducted inside the subject's work office. Analysis has shown that this factor was highly stressful.

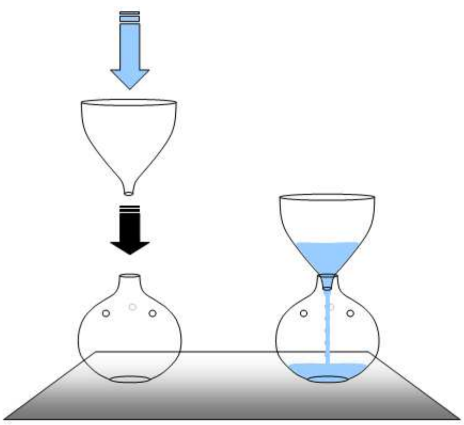

Fig. 2. The clepsydra designed by Fauquet-Alekhine for use during Stress-test taken by a subject who must perform a given task (Fauquet-Alekhine et al, 2011). The two receptacles of the clepsydra are put together and the water flows from the upper part to fill the bottom part until the holes are reached. Then the water will flow out of the clepsydra.

2.2.Elaboration of the Stress-test conditions : the 3-level qualitative scale

To elaborate the conditions, a 3-level qualitative scale (3-LQS) has been developed and applied based on work activity analysis, using stress variables within a 3-D source space (context, request or job demand (excluding context), subject's characteristics) close to previous works (McLean, 1974; Karasek et al., 1990, 1998) linked to a 3-D symptoms space (physiological, psychological, behavioral) as detailed in Fauquet-Alekhine (2011, 2012a and especially 2012b): we made the demonstration that short term mental occupational stress could only be correctly modelized if the stress consequences were taken into account.

The 3-level qualitative scale has been built on the basis of an a priori task analysis in order to identify the parameters involved or not in the stress. For this aim, the work activity analysis has been conducted in two steps:

- a macro approach identifying macro-variables to describe the stress conditions,
- a refined description of those macro-variables with variables to be identified, and an evaluation of these variables as parameters contributing to the subject's stress.

Proceeding with two steps was better: it helped the analysis to focus observations on each field bounded by a macro-variable, made the analysis more efficient by focusing then on each one, and led to a more efficient description and evaluation of the variables.

The following Table I describes the macro-variables and gives the link with their respective stress dimensions.

Based on the studies done in the field of stress at work (see previous section) and our own experience, 8 macro-variables have been retained and named to describe and manage the conditions of short term occupational stress.

It must be kept in mind that it would be different for others cases of stress: others parameters come into account for long term stress or if the stress is not principally linked to the job.

These macro-variables can be used to widely describe short term stress induced on the subjects in work situations, and match the parameters used in other studies to describe stress conditions. In this study, each macro-variable has been broken down into several variables that will be described below; these variables are a refined level of description and have the possibility to vary from a no stress level to a stressful level. For example, considering the macro-variable "environment", we might be in a case for which the variable "color of the room" is relevant: a soft colored room is rather relaxing, while aggressive colors will be supposed to stress people.

Of course, as reminded in the NASA review of Staal (2004), "stress" is a term that can be applied to any demand to a system. This means that "any task that requires mental resources qualifies as a stressor". This must be understood as: "we ask, we stress", but we stress at a different intensity according to the specificities of the request and all the other variables linked with the request. Thus, as explained before, we must not think the "no stress level" of a (macro)variable as a level characterizing an absence of stress, but it must be understood as the low limit of the (macro)variable which could potentially be reached.

Table I. Identified the macro-variables for short term occupational mental stress during Stress-test and training sessions.

Macro-variable	source dimension concerned	Description of the macro-variable
T: task	job demand dimension context dimension	Describes the task which has to be done, level of feasibility, task goal, organization and means, time length.
D: documentation	context dimension	Describes the quality of the documents used by the subject to do the task.
P: place	subject's characteristics dimension context dimension	Describes what means the place for the subject, regardless to the following activity (association with some jobs done there before in such a place; if unpleasant activities, then stressful).
SS: social support	context dimension	Describes all relationship with people link with the task during the job.
S: subject	subject's characteristics dimension	Describes feelings and states of the subject which are known.
M: metrology	context dimension	Concerns the metrology which is necessary used for the present experiments.
E: environment	context dimension	Describes environmental conditions.
AD: additional factors	all dimensions	Concerns some factors which can be added according to the situation.

Each macro-variable is made up of variables, which are evaluated as a first approach on a 3 unit scale:

- no stress: it seems to have relaxing or reassuring character, and it will likely be significant during the activity, for most of the subjects,
- medium : it seems to have neither any stressful character, nor relaxing properties, and it will probably be stable during the whole activity, but can significantly vary from one subject to another depending on the subject themself,
- stress: it seems to have stressful character, and it will likely be significant during the activity, for most of the subjects.

These three levels are used to describe a priori the effect of each variable on the psychological state of the subject in a qualitative approach. Evaluating these variables according to this qualitative scale has helped to build the two kinds of conditions of the Stress-test as a first approach. The evaluation of these variables can be refined later, but the only way to refine them is to make the subjects answer an adapted perception questionnaire of stress including these variables. During the conception of the task, it is difficult to be more accurate than this 3-level qualitative scale: at this stage, we can only postulate when the variable intensity will rather be relaxing, neutral (medium intensity) or stressful.

It must be noticed that the 3-level qualitative scale is a major tool, and works according to simple rules. It is of great importance to remark that the identification of the (macro)variables, their description or their label, the accuracy of the way they are refined, are not as important as the exhaustiveness of the whole. Here, exhaustiveness means that all the relevant parameters of stress must be taken into account within the (macro)variables. Identification, description and label, can be done differently from one work analyst to another for one given activity; the main point is to build a pertinent 3-level qualitative scale and have a sufficiently refined analysis of the activity or at least of the task to reach a right evaluation of each variable level. The rules for the 3-level qualitative scale are: exhaustiveness combined to pertinence, and correct level evaluation.

To illustrate these rules, we shall give short examples:

Exhaustiveness and pertinence lead to the identification of variables: we wrote that it can be different from one specialist analysis to another, and that it will not spoil the final results. This is true provided that exhaustiveness and pertinence will both characterize this identification. For example, two analysts can think about tool ergonomy of the work activity. One of them will think that it concerns the macro-variable Task, the other the macro-variable Environment. Here, no matter which macro-variable includes the ergonomy, the main thing is to include it within the scale if it concerns the activity with a relevant link. But is it really relevant? If not, we must not hesitate to banish it from the scale which must be exhaustive but meaningful, not overloaded. We can illustrate it with the application to the case of the task built for the Stress-test: subjects have taken the test in their job office; they will have to sit on their daily chair, and work with a pen, reading papers. In this case, ergonomic problems do not occur: on the 3-level qualitative scale, ergonomy is considered irrelevant because it will have neither any significant stressful character, nor significant relaxing properties (nothing is especially done for this purpose), and it will be stable during the whole activity, and so from one subject to another.

Exhaustiveness does not mean that every parameter of stress must appear on the scale: it must be relevant according to the activity studied.

As we can see on Table 1, the (macro)variables concern both the 3-D spaces described in the previous section (source and consequences), but can be only described a priori inside the 3-D source space.

The results of the 3-level qualitative scale giving the a priori description of the Stress-test conditions are described in the following Tables 2 and 3. It has been obtained by refining the macro-variables into variables which description is done here after, for which we explain two extreme states concerning respectively No Stress and Stress conditions, using the 3-level qualitative scale.

Table II. Identified variables for short term occupational mental stress during Stress-test in No Stress Conditions and evaluation on the 3-level qualitative scale

Case of No Stress Test

Dimensions	no stress	medium	stress
T task level : easy - difficult	1	1	
T task level : known - difficult or unknown		1	
T task objective : clear - undefined or fuzzy	1	1	
T task means : adequat - none or insufficient		1	
T task organization : adapted - not sufficient or not adapted or new		1	
T task : length : short - long		1	
T task time constrains : without - with	1	1	
T briefing task : helpful - useless	1	1	
D doc : helpful - erroneous		1	
D doc : understandable - complex	1	1	
P place : linked with easy task - linked with difficult task	1	1	
P place : known - unknown	1	1	
SS social support : peer - subordinate		1	1
SS social support : helpful - agressive	1	1	
SS social support : eval.with consequences - eval. with no consequences	1	1	
SS social support : quiet - disturbing	1	1	
S subject competence perception : good or upper level - low level	1	1	
S subject physical state : good - bad		1	
S subject psychological state : good - bad		1	
S subject risks perception for others : with - without		1	
S subject self risks perception : with - without		1	
S subject autonomy peception : possible - impossible	1	1	
M metrology : none or invisible - disturbing		1	
E environment sound : calm - noisy	1	1	
E environment view : not agressive - agressive		1	
E environment smelling : normal - heavy		1	
AD additional factors = Ant et Post factors APF		1	
AD additional factors : others			
description of additional factors			clepsydre

Table III. Identified variables for short term occupational mental stress during Stress-test in Stress Conditions and evaluation on the 3-level qualitative scale

Case of Stress Test

Dimensions	no stress	medium	stress
T task level : easy - difficult		1	1
T task level : known - difficult or unknown		1	
T task objective : clear - undefined or fuzzy	1	1	
T task means : adequat - none or insufficient		1	
T task organization : adapted - not sufficient or not adapted or new		1	
T task : length : short - long		1	
T task time constrains : without - with		1	1
T briefing task : helpful - useless		1	1
D doc : helpful - erroneous		1	
D doc : understandable - complex		1	1
P place : linked with easy task - linked with difficult task		1	
P place : known - unknown	1	1	
SS social support : peer - subordinate		1	1
SS social support : helpful - agressive		1	1
SS social support : eval.with consequences - eval. with no consequences	1	1	
SS social support : quiet - disturbing		1	1
S subject competence perception : good or upper level - low level	1	1	
S subject physical state : good - bad		1	
S subject psychological state : good - bad		1	
S subject risks perception for others : with - without		1	
S subject self risks perception : with - without		1	
S subject autonomy peception : possible - impossible		1	
M metrology : none or invisible - disturbing		1	1
E environment sound : calm - noisy		1	1
E environment view : not agressive - agressive		1	
E environment smelling : normal - heavy		1	
AD additional factors = Ant et Post factors APF		1	
AD additional factors : others			1
description of additional factors			clepsydre

As said before, the appreciation of the level is made by the specialist, a work analyst, from his/her own point of view according to the way s/he built the conditions for the parameter to induce stress or not, except for those of type "S subject". For example, if the task is made for a subject in agreement with his/her skills and competence, according to what such a subject is expected to know and to be able to do, the specialist will identify the task level as "easy", which will match "no stress" on the scale. On the other hand, if the specialist identifies a task which cannot be done easily according to the knowledge and competence of the subject, s/he will identify the task level as "difficult", which will give "stressful" on the scale. In the case of the task is concerned by the variable, but for which no a priori estimation of effect on the potential level of stress is possible, then the level chosen is "medium".

2.3.Perception of Stress

The perception questionnaire of stress used for this experiment (the Post Disorder Inventory or PDI questionnaire) has been elaborated earlier in order to obtain a quantitative measure of the level of distress experienced, tested by several including in its French form (see Jehel et al., 2005 and 2006). This questionnaire has been chosen after having studied several questionnaires for self-rating of stress, established and scientifically tested. The Job Content Questionnaire of Karasek has not been retained here because, even if the variables are watched through the items, some questions do not concern the Stress-test or the training sessions, and some variables, which are relevant to be asked, are not investigated by the questionnaire. The Cohen’s Perceived Stress Scale (PSS) (Cohen et al., 1983) as the more recent Work and Well-Being Questionnaire (Kilminster et al., 2007; Bridger et al., 2011), concern the long term stress and thus is not adapted to this study. The State-Trait Anxiety Inventory (especially the STAI form Y-A self-rating the subject’s anxiety state) developed by Spielberger (1983) has not been used because it measures anxiety with too few reference to exogene parameters.

For the present study, the PDI questionnaire was used immediately after taking the test. The subjects were asked to answer each question according to a 5 levels Likert type scale: not at all, a few true, rather true, very true, extremely true. The questionnaire was used in French (see appendix). The translated questions are listed below:

01-I felt helpless to do more
02-I felt sadness and grief
03-I felt frustrated or angry I could not do more
04-I felt afraid for my safety
05-I felt guilt that more was not done
06-I felt ashamed of my emotional reactions
07-I felt worried about the safety of others
08-I had the feeling I was about to lose control of my emotions
09-I had difficulty controlling my bowel and bladder
10-I was horrified by what happened

11-I had physical reactions like sweating, shaking, and pounding heart
12-I felt I might pass out
13-I thought I might die

2.4.The protocol

The protocol applied to generate the test conditions is described in Table IV, each column referring to a given condition. Each line of Table IV describes one step of the protocol and the difference between the two conditions can be easily understood.

Table IV. Comparison of the two Stress-test conditions.

Stress Conditions for the Stress-test	**No Stress Conditions for the Stress-test**
The researcher presented the test as a set of twelve questions to be answered as fast as possible, in a time presented as limited by the clepsydra that will be charged with water (Fauquet-Alekhine et al., 2011). It is explained that the clepsydra has holes that will pour water on the desk if it is not stopped soon enough corresponding to the time the subject will finish the test: thus, the subject must answer fast, and no information is given concerning the given time.	*The researcher presents the test as a set of twelve questions to be answered without any limit of time. Nothing is said concerning the clepsydra as it is not used.*
The researcher informs the subject that, during the test, the monitor will be worn on the wrist, and that it will give out a beep when the heart rate rises over a given threshold.	*The researcher informs the subject that, during the test, the monitor will be on the table in order the make some measurements of heart rate. Nothing is said concerning the beep as it will not be used.*
The subject is asked to be involved in the test until the end: if s/he accepts to begin, s/he engaged her/himself to achieve the test. The subject is said "alone": it means s/he will not have any possibility to ask any question during the test. If a question seems too difficult, s/he can go further, then come back to this question, or leave it. When the subject decides that s/he reaches the end, the heart rate monitor is stopped.	*The subject is asked to be involved in the test until the end: if s/he accepts to begin, s/he engaged her/himself to achieve the test, but subject is not "alone": it means s/he will have all possibility to ask the researcher any question during the test. If a question seems too difficult, s/he can go further, then come back to this question, or leave it. When the subject decides that s/he reaches the end, the heart rate monitor is stopped.*
In both cases, the mean and maximum heart rate at rest sitting are checked.	
Before beginning taking the test, the researcher sets the monitor at a low threshold to produce a beep very quickly. It means that the parameter value will be chosen according to the maximum heart rate just measured at rest. The monitor is put on the subject's wrist. Usually, a few seconds after beginning the test, the monitor beeps.	*The researcher leaves the monitor on the table. It will not do any beep.*
Then the test begins, and water is poured inside the clepsydra: water begins to flow and makes very rapidly the noise of a liquid stream hitting a surface of water.	*Then the test begins.*
Meanwhile, the researcher paces up and down in front of the subject.	*Meanwhile, the researcher takes a sit close to the subject, reminding that he is ready to answer any question.*
During the test, the water inside the clepsydra stops just under the holes: the quantity of water has been calibrated in order not to wet the desk. The researcher then says: "I did not put enough water, but anyway, you must hurry up"; he orders it severely. Usually, it happens before question #7.	*The researcher is just waiting for some questions. If there is no one, he reminds gently to the subject this possibility.*
Meanwhile, the researcher keeps on pacing up and down in front of the subject.	*Tthe researcher is just waiting for some questions.*
When the subject reaches the question #10, the researcher says "now, hurry up, please". As before, he orders it severely.	*During the test, the researcher is just waiting for some questions. If there is no one, he reminds gently to the subject this possibility.*

To avoid any bias due psychological interferences as observed for example with the Stroop effect (see studies of Mathewson et al. (2010) which concern performance of a pictorial Stroop task), the questionnaire presented is written in black ink on white paper.

2.5.The Stress-test questionnaire

The Stress-test is made up of 12 questions. A performance coefficient, based on the right answers given by the subject, is calculated for each subject. This performance coefficient is related to the subject's stress, according to lots of research works. Subjects must answer all the questions, but only 9 questions are used for analysis because 3 of them involve the cultural affinities or the ability to calculate (they are used in the test in order to make the subject think not only about logical problems). For example, somebody who is used to traveling in Africa or America will have more problems to know in which country is Minsk than somebody traveling in ex-soviet union every year. Concerning calculation, somebody who makes mistakes can nevertheless reach the right results, which is not necessarily a matter of stress.

The test itself has been designed to be taken in 5 to 15 minutes. Considering that we must spend time with the subjects to present the test at the beginning of the meeting, and after the test we ask the subjects to fill questionnaires, the whole time spent with the subjects is about 30 to 45 minutes. As we ask them to take the test on their place of work, i.e. their office, (in order to fix this environmental factor of the task variable), it is welcome to make this time less than one hour (less than one hour is acceptable; if more, we should take too much of their time and subjects would not accept the test).

The questions asked for the Stress-test are the following types:

1) Link together numbers on two lists of six numbers each (on one side, one has no correspondence, and another is written twice).
2) Raven's progressive matrix: 3 series of 3 patterns, one missing to be found on the last line.
3) Logical series: for each of the 3 series, find the next value.
4) Calculation test: a temperature is increased twice by 10%, so finally it has increased by 20% of the initial value - right or wrong?
5) Cogs: one of them turns in a given way, which way does the last one turns?
6) Cogs: same task than #5 but a bit more complicated.
7) Perceptive test of reading: read the 3 lines of capital cursive text and find how many 'V' are in the text.
8) Language test: link French word with corresponding foreign word (5 words of each).
9) Language test: encircle the odd word out among 5 foreign words.
10) General culture test: link towns with corresponding countries (5 of each).
11) General culture test: link towns with corresponding countries (5 towns, 7 countries, and some of them have no link; 1 town and 3 countries).
12) Speed test: put in alphabetic order 12 letters presented on one line, in capital letters (one is written twice).

Among these items, #4, 10 and 11 are not used for the calculation of the score because, as said above, they involve the cultural affinities or the ability to calculate.

2.6. Application to nuclear reactor pilots

Analysis of French nuclear pilots training ($N > 100$) is done below using the qualitative scale. This is done in order to evaluate the appropriateness of learning conditions (concerning the effects of stress) with the possibility of the trained people to find appropriate conditions of learning.

The purpose is to use the 3-level qualitative scale a posteriori for simulation training analysis, while it has been done a priori for the stress-test.

The training of French nuclear pilots is scheduled in 5 steps, involving 123 days spread over 15 months, both in room and on simulators. The training in room consists of conceptual and theoretical knowledge, and of description of the installations and materials. The training on simulators consists of two parts, one on the simulator itself, and one in room to discuss what has been done during the simulated situation; 3 hours are devoted to each part.

There are three kinds of simulators: part simulator, full scale simulator, and virtual simulator. The full scale simulator reproduces the full control room of a reactor, with a refined simulation of the physical parameters of the process. The part simulators are parts of the full scale simulator; they are used to focus on a specific part of the piloting system; for example, one of the part simulators concerns the feeding-extracting system of the process (RVC mini simulator). The virtual simulator consists of computers performing software reproducing physical parameters; the installation is designed on the screen, and water and coil are visible inside components; values of the physical parameters are shown according to the process in progress.

The five steps of the French nuclear pilots training are:
CFTR: Conduite Formation Théorique Réacteur à Eau Pressurisé
(Theoretical training for Pressurized Water Reactor)
COSN: Conduite en Situation Normale (Operating in normal situation)
COSP: Conduite en Situation Perturbée (Operating in disturbed situation)
CAPE: Conduite en Approche Par Etat (Operating in accidental situation)
CRSN: Conduite Retour aux Situations Normales (Back to operating in normal situation)

Their characteristics are described in Table V.

Table V. Description of each step of the training cycle for French nuclear reactor pilots.

Training type	**description**	**room training**	**simulation training**
CFTR (60 d. distributed on 6 m.)	Understanding the industrial process from a technical and theoretical standpoint	10 w. (by a 1 or 2 w. periods)	Part simulators (3 types, 1 w. each) + full scale simulator (2x1w.)
COSN	Operating in normal situation: watching in control room understanding piloting in control room	1 w.	full scale simulator (by 1 w. period)
COSP	Operating in disturbed situation: watching information in control room diagnostic and decision applying actions control	1 w.	full scale simulator (by 1 w. period)
CAPE	Accidental situation: trusting procedures understanding procedures structures and actions applying procedures	3 d.	full scale simulator (5x1w.) + virtual simulator (3x1w.)
CRSN	Back to operating in normal situation: reminding the COSN adapting training to the pilots'needs specific plant feedback	0	3 d.

(d = day; w = week; m = month)

The four first steps are closed by an evaluation. On the chronological scale plotted below, it happens after about 6 months, 8, 10 and 14 months.

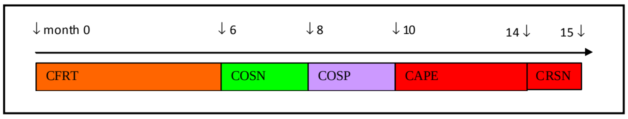

Fig. 3. Chronological cycle of French nuclear reactor pilots' training.

To rate the state of stress evaluated with the 3-level qualitative scale, we introduce the relative stress balance. It is calculated by doing the difference between stress and no stress variable, normalized by the number of variables potentially involved in the activity as stress or no stress variables. Then, we compared to the results obtained by the futures pilots trained on the French nuclear plant of Chinon during a given 15 months training cycle. For this aim, the compiled data concerning 2010 and involving more than 100 subjects have been analyzed.
It is important to notice here that the use of the 3-level qualitative scale has been applied independently of the results data analysis, to avoid any influence of the results on the scale appreciation.

2.7. Application to anesthetists training

After qualification of the protocol and device with the Stress-test, applications have been done to full scale simulation trainings for French anesthetist residents in a Paris district hospital (*N*=27) using the 3-LQS and physiological measurements.

Students were involved in a one day training session in operating theatre, and training was performed the whole week (5 days). It means one different group of about 6 students was received every day. At the end of the week, 27 French students have been trained, played different role depending on the scenario.
Four different scenarii were used per day (less than one hour each), and 3 students were training together per scenario, each scenario (about 30 minutes) followed by a debriefing session (30 to 45 minutes).

The participants of the simulated situation for a scenario were:

- 3 students playing the role of physician, nurse, and help,
- 1 physician trainer, playing the surgeon,
- 1 physician trainer piloting the simulator.

The scenarii were clinical cases involving only one dysfunction (no cumulative cases). The 4 scenarii were:

- Asphyxia related to post-operative cervical hematoma,
- Local Anesthetics intoxication,
- Peroperative third degree auriculoventricular block,
- Peroperative respiratory arrest related to injection of myorelaxant drug.

3. Results & discussion

3.1.The Stress-test experiments

Using the 3-LQS of stress, two conditions of the Stress-test have been built up, No Stress and Stress Conditions, for which the following radar graphs show the obvious difference expected (Fig. 4 a & b).

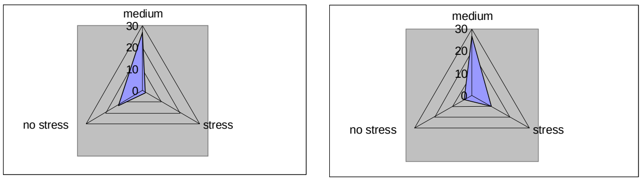

Fig. 4 a & b. The 3-LQS evaluation of the Stress-test conditions.

In order to verify whether the heart parameters can reflect the state of stress as exposed by others and reminded above, we have done a modal analysis of the mean heart rate, HR_{mean} , and of the maximum heart rate, HR_{max}.
This modal analysis has been done according to modes defined as follows, expressed in bpm :
[-inf; 50[, [50; 65[, [65; 80[, [95; 110[, [110; 125[, [125; 140[, [140; +inf[

For each interval, we have calculated the proportion of values included in, and we have drawn the values versus the 7 modal intervals, for HR_{mean} on one hand, and for HR_{max} on the other hand. The process has been done separately for Stress Conditions subjects, and No Stress Conditions subjects, represented on one graph as different bars (Fig. 5).
The results clearly show that Stress Conditions subjects present higher values than No Stress Conditions subjects, in both cases, HR_{mean} and HR_{max}.

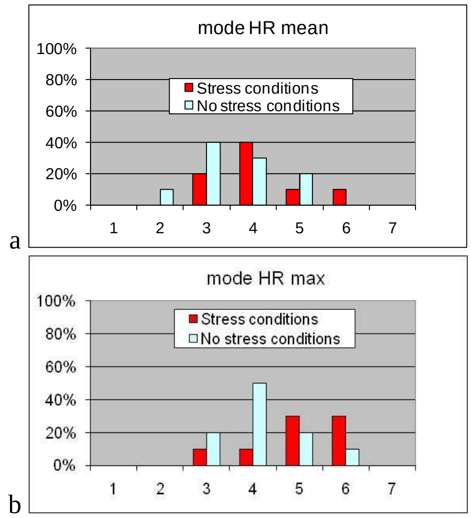

Fig. 5a & b. Modal analysis of HR for mean and max values during the Stress-test

We thus validate the previous results cited above ("Background" section), claiming that for short term occupational stress, heart rate increases. And, according to the analysis presented above and showing the importance of the mean and maximun heart rate, we accept HR_{mean} and HR_{max} as relevant physiological parameters for state of stress characterization.

From a qualitative standpoint, we can notice that these heart rate values are depending on the physiological state of the subject. We can then decide that the physiological dependence of HR_{mean} can be expressed by considering the increase from a basic value which is usually the heart rate at rest for a subject lying down, $HR_{mean\ rest\ lain}$; this parameter is used to being measured when the subjects has been lain for ten minutes.

Considering the same kind of dependence for HR_{max}, we must notice that this value is reached because the heart rate increases under Stress Conditions, and as more as HR_{mean} is high, as more the probability of HR_{max} to be high is important (Fig. 6). We then suggest to consider a relative value of this increase in terms of the difference between HR_{mean} and HR_{max}, noted $HR_{max\ ampl}$.

The modal analysis for the values of

$$(HR_{mean} - HR_{mean\ rest\ lain})$$

on one hand, and of

$$HR_{max\ ampl}$$

on the other hand, is done according to modes defined as follows, expressed in bpm :

[-inf; 5[, [5; 10[, [10; 15[, [15; 20[, [20; 25[, [25; 30[, [30; +inf[

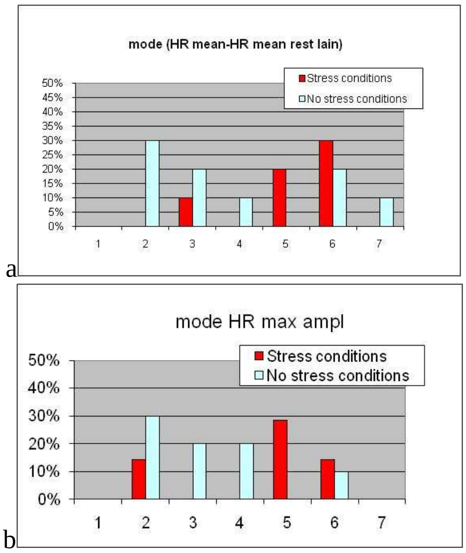

Fig. 7a & b. Modal analysis of delta HR values obtained during the Stress-test

The results clearly show that Stress Conditions subjects present higher values than No Stress Conditions subjects, in both cases. Yet, the discrimination of both states of stress is less marked for $HR_{max\ ampl}$. Nevertheless, we shall prefer these parameters than the previous ones because they take into account the physiological characteristics of the subjects.

We thus accept $(HR_{mean} - HR_{mean\ rest\ lain})$ and $HR_{max\ ampl}$ as relevant physiological parameters for state of stress characterization.

For further analysis, we need to build a stress coefficient that will take into account this double relationship. We can formulate it as follows:

- The stress coefficient is
  $$f(\ HR_{mean}, HR_{max}, HR_{mean\ rest})\ ,$$
  where $HR_{mean\ rest}$ designates a reference HR at rest which can be lying down or sat,
- The stress coefficient varies as HR_{mean}, as HR_{max}, as $(HR_{mean} - HR_{mean\ rest})$, and as $HR_{max\ ampl}$
- Physiological consideration suggest to consider relatives values rather than absolute values for heart rate parameters, which engage us to build the stress coefficient as a function of $(HR_{mean} - HR_{mean\ rest})$ and $HR_{max\ ampl}$ rather than a function of HR_{mean} and HR_{max}.

We thus formulate the stress coefficient as follows:

$$f(\ HR_{mean} - HR_{mean\ rest}, HR_{max\ ampl})$$

From a strictly mathematical standpoint, we can make the assumption that K_s varies as the result of the increase of HR_{mean} from $HR_{mean\ rest}$, and $HR_{max\ ampl}$. It leads to introduce a stress coefficient K_s written as:

$$K_s = (HR_{mean} - HR_{mean\ rest})\ .\ HR_{max\ \mathrm{ampl}}$$

In order to know if K_s can reflect the state of stress, we have done as above a modal analysis according to modes defined as follows, expressed in bpm^2 :

[-inf; 50[, [100; 200[, [200; 300[, [300; 400[, [400; 500[, [500; 600[, [600; +inf[

For each interval, we have calculated the proportion of values included in, and we have drawn the values versus the 7 modal intervals, for K_s in No Stress Conditions on one hand, and for K_s in Stress Conditions on the other hand, represented on one graph as different bars.

The results show clearly that Stress Conditions subjects present higher values than No Stress Conditions subjects, in both cases, as obtained for previous heart parameters (Fig. 7).

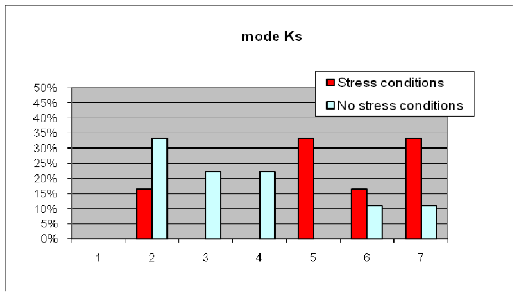

Fig. 7. Modal analysis of the coefficient of stress during the Stress-test

We thus validate the stress coefficient defined as:

$$K_s = (HR_{mean} - HR_{mean\ rest}).HR_{max\ ampl}$$

We shall see further that this coefficient can be simplified from a mathematical standpoint and some pragmatic considerations.

As explained above, a score is calculated to evaluate each subject’s success taking the test: one point is attributed for each right answer. Nine answers are considered, and a mean value is calculated to give the performance coefficient for each subject.

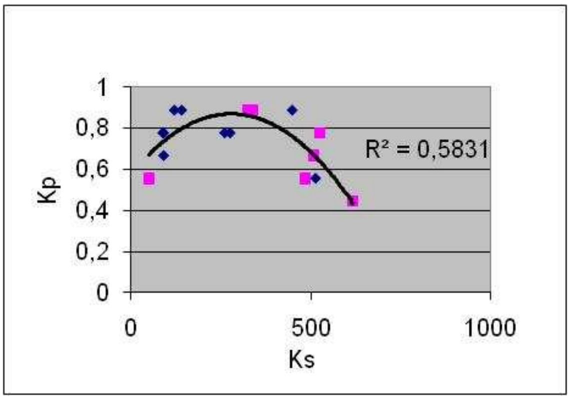

Fig. 8. Performance coefficient K_p plotted vs stress coefficient K_s discriminates the No Stress Conditions (dark diamonds) and the Stress Conditions (clear scare) for the Stress-test' subjects

The performance coefficient plotted versus the stress coefficient K_s gives an inverted U curve (Fig. 8), which is not without reminding the Yerkes curve type (Yerkes & Dodson, 1908).
The coefficient of determination is rather good: R^2=0.58 p<0.01)
To evaluate the robustness of the correlation, a F-test has been done with the null hypothesis that the model fits the experimental data. Calculation gives $F(1,28)$=0.85 for a critical value $Fcrit(1,28)$=7.62, p=0.01. The null hypothesis cannot be rejected and the correlation is kept as acceptable.

Furthermore, the graph discriminates the No Stress Conditions (dark diamonds) and the Stress Conditions (clear scares). If we consider the set of dots as a global image of the state of stress of people, and if we consider the median value as the threshold between two parts of the sample, one stressed and one not stressed (as done by others; see for example the DARES report, 2008), we shall find that this threshold corresponds to the flattering off of the bell graph, with more than 81% of the subjects on the right side of the plateau according to the test they respectively took.

These elements lead to several conclusions:

- The tasks built for the test are actually of two kinds: No Stress Conditions and Stress Conditions, as the subjects finally show two states of stress clearly separated materialized by the flattering-off threshold. This leads to the conclusion that the 3-level qualitative scale used to create the conditions of test is effective and confident.
- The curve drawing the performance coefficient versus the stress coefficient *Ks* gives a satisfactory description of the stressed state of subjects, and of their linked performance, and it matches the Yerkes model: more the subject is stressed, more s/he will be efficient, until a threshold of stress over which the subject will enter a cognitive disorder zone that will reduce her/his performance.

We must yet consider the pragmatic side of the method. We claimed that our purpose is to develop a simple protocol, requiring basic metrology and simple straight data analysis, to be used on training simulators by the instructors, who are not necessarily experts in medical researches. One problem then appears: the measurement of the heart rate at rest when the subject is lying down. In situations of training sessions on simulators, observations show that this operation is not easy. We have seen several cases for quite different professions, and every time, this parameter is not measurable within the time of the sessions:

- For all cases, training sessions are overloaded and do not allow to spend ten minutes to measure the heart rate at rest.
- In most cases, no place devoted to such rest exists. Even if a rest room is made available for this purpose despite the problems of space in industrial or training centers, it will be for one person, and one session involves four to six persons for the nuclear reactor pilots, eight for the anesthetists, at least two for pilots of civil planes or harbor pilots: this means 20 to 60 minutes to be spent just for this measurement.

There is one solution that consists to try to find another heart rate parameter at rest: for example, we could choose the one measured during our test, just before taking the test (as described in the section presenting the protocol). But it has been observed that some of the subjects were stressed before taking the test, during the introduction speech (Fig. 9). It was assumed that this could be linked with the young age of the subjects, but the graph below, comparing both heart rate at rest lying down or sitting (in bpm) versus the subject age (in years) shows that it is not the case, but depends on the subject themself. Thus, the heart rate at rest for the subject sat just before the test cannot be kept as a valid reference heart rate.

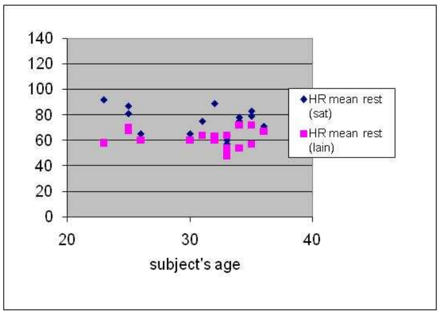

Fig. 9. HR at rest for the Stress-test' subjects

There is another solution that consists to ask the work physician to make such measurement during the annual check-up, but he will opposed that, as others, his time is too short to do all he has to do.

Another solution consists to ask all trainees to perform this measurement by themselves at home, for example in the morning, before getting out of bed. But you can be sure that the reliability of the data will be doubtful or for some of them, you will not have any value. To illustrate this point, we shall just take a few lines to explain what happened with the present test. At the end of the test meeting, subjects have been asked by the researcher to

perform by themselves their own heart rate at rest. For this purpose, they have been asked to measure their heart rate during one minute, in the morning while waking up after sleeping at night, before leaving the bed. For more than the half subjects, the value was given into the week following the test. For a quarter of them, it occurred in several weeks, and for the last quarter, it took more than six months and was obtained after lots of recalls by email, phone and sms! All this induced a delay on our research.
For these reasons, we think that it is of great interest to introduce the reduced stress coefficient K_{sr} that does not integrate the heart rate at rest, and to check its solidity (Fauquet-Alekhine *et al*., 2011).

The reduced stress coefficient K_{sr} is defined as follows:

$$K_{sr} = HR_{mean} \, . \, HR_{max\ ampl}$$

The performance coefficient plotted versus the reduced stress coefficient K_{sr} also gives a Yerkes curve type (Fig. 10). As for the K_r curve, the graph discriminates the No Stress Conditions (dark diamonds) and the Stress Conditions (clear scare). We must notice that the correlation is of the same order but slightly better (with a better coefficient of determination is R^2=0.69), and, more important, that the subject dots are characterized relatively to the others at same level (or not significantly far): in fact, introducing the heart rate at rest does not bring a valuable gain in terms of characterization of the subject's performance-stress inside the group.

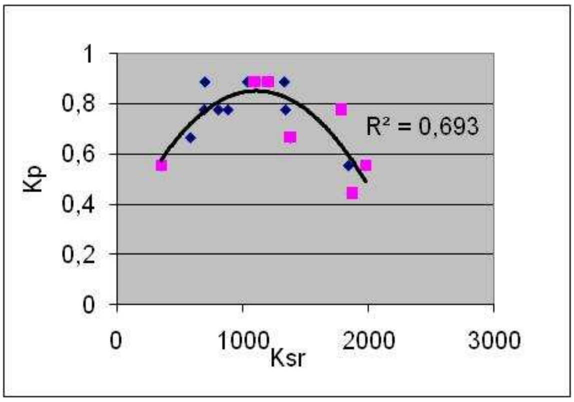

Fig. 10. Performance coefficient K_p plotted vs reduced stress coefficient K_{sr} discriminates the No Stress Conditions (dark diamonds) and the Stress Conditions (clear scare) for the Stress-test' subjects

Conclusions are:

- We demonstrated that a representative stress coefficient can be elaborated from the measurement of mean and max amplitude of the subject. These parameters are easily measurable by a classic heart rate meter provided in ordinary sport shops.
- This coefficient gives a good representation of the subject's state of stress during a work activity in which mental stress is involved, which means without physical stress.
- The subject's heart rate at rest can be used to calculate the stress coefficient, but does not give more information concerning the subject's state of stress according to the sample of subjects (narrow age interval). Thus, as it takes time to obtain this parameter, and as, in some application configurations, it can be difficult to ask people to lie down in order to have a rest before measuring the heart rate, the conclusions allow to use the stress coefficient without the heart rate at rest.

3.2.Application of the 3-LQS to French nuclear pilot training

Application of the 3-LQS for the French nuclear pilots training in order to evaluate the appropriateness of learning conditions have led to the assumption that some difficulties could occur at the end of the training cycle: Fig. 6 a & b permits a comparison between variation of stress at different stages of the training period using the 3-LQS rating, and results obtained by the French nuclear reactor pilots taking exams for the three last stages; it shows a similar variation, decreasing with time.

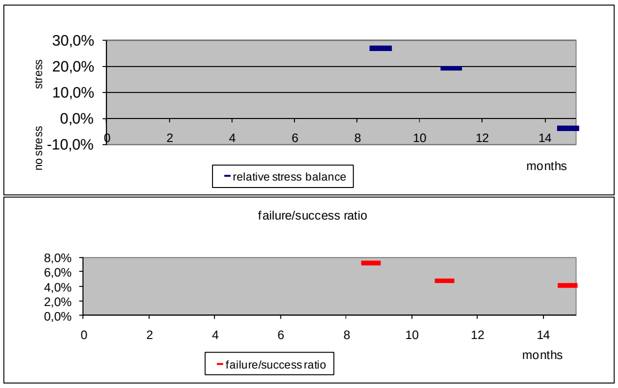

Fig. 6a & b. Comparison between variation of stress (upper graph) and results for the French nuclear reactor pilots (bottom graph) during the training cycle (X-axis expressed in months); they show a similar variation, decreasing with time.

The correlation coefficient (Fig. 7) related to the evaluated stress balance by the 3-LQS and the failure/success ratio at the pilots' exam along the training period is r=0.83, p<0.05.

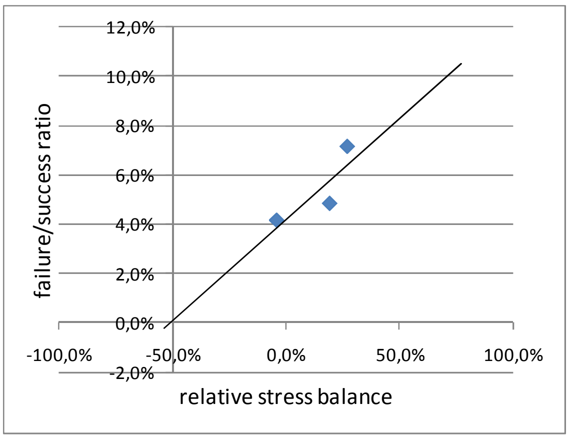

Fig. 7. Correlation coefficient related to the evaluated stress balance by the 3-LQS and the failure/success ratio at the French nuclear reactor pilot's exam along the training period.

Figure 7 suggests that the full success (0% for the failure/success ratio) might be reached at -50% on the relative stress balance axis (intersection of the fitted curve with the X-axis). Further studies based on the 3-LQS indicate that, in order to reach -50% of relative stress balance for the training, the variables to be worked are the self-confidence, the task definition, and mainly the documentation arrangement.

Individual interviews of a several pilots have then been conducted. They have been asked what was the more difficult step in the initial training cycle, and why. They all agreed that the more difficult was the COSP (disturbed situations) occurring between the eighteenth and tenth month. They explained that is was simulations of difficult situations because disturbed, and not frequently encountered in non-simulated situations. These rare situations imply to use procedures which are not often applied. So they are not well known by the pilots, and less ergonomic. This last specificity seems to be due to the fact that they are less used, so less adjusted to the user by the writer since the user makes less remarks concerning those documents compared to others daily used. The result is that COSP offers to the pilots disturbed situations to be dealt with complex and non-ergonomic procedures, with little feedback from the experienced colleagues in the daily work since these are rare situations.

One could say that it is now time to proceed to some experiments with heart rate meter during the nuclear reactor pilots' training. Obviously, this would be of great interest to reach more accurate conclusions than the above.
Unfortunately, this is not possible, especially for reasons of policy: the past five years have been a period of hard negotiation between the union trades and the company direction concerning the periodical evaluation guidelines of reactor pilots. This case is too fresh in mind for science to come and study what is going on during pilots' tests: results could be used for policy objectives and interpreted by others in a way we would not agree with, without the possibility of making changes. To proceed to such studies, ethic conditions must be clearly defined at first with all those implicated.

3.3.Application of the 3-LQS and performance vs stress analysis to anesthetist's training

Application of the 3-LQS for anesthetist residents' training has detected stressful conditions (Fig. 8).

Application of the developed protocol studying performance vs stress (qualified with the Stress-test) has confirmed stressful conditions, showing that most of the subjects were in a cognitive disorder zone on a K_p vs K_{sr} graph of Yerkes type curve (see Fig. 9), on the right side of the bell graph.

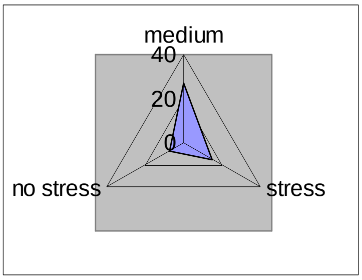

Fig. 8. The 3-level qualitative scale radar graphs applied to the anesthetist residents' training.

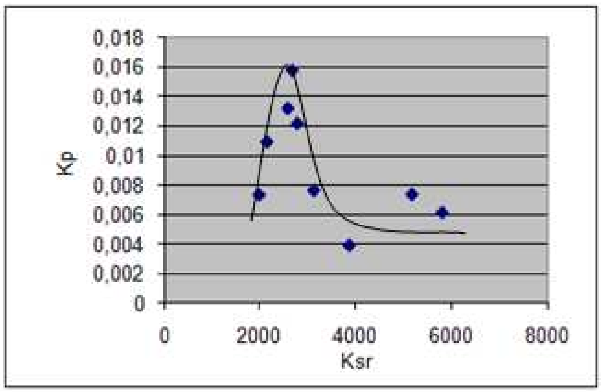

Fig. 9. Performance coefficient K_p plotted vs the reduced stress coefficient K_{sr} in case of anesthetists' full scale simulator training.

Analysis of the factors leading to stressful conditions done with the help of the 3-LQS shows that residents need to be more familiar with the simulator and with the activity before being involved in this kind of working situations.

3.4.Comparative analysis

Comparison between both trainings, and analysis done for each, have led to suggest improvements for each profession.

It has been noticed that weaknesses for one may be a factor of no importance for the other. For example, confidence in documents in real time for nuclear reactor pilots appears a necessity for them and the lack of confidence is thus a weakness. On the contrary, anesthetists do not care as they use their memory: having procedures in surgery theatre and reading them during the operation is not compatible with the work. Thus, the induced stress due to documents for pilots is not effective for anesthetists.

It has been noticed that some stress variables are not dealt with in the same manner. For example, pilots are progressively trained on simulator which makes them progressively familiar with the simulator while the anesthetists discover the simulator when trained.

For anesthetists' training, the main point of improvement would be thus to make them familiarized with the simulator before the training session itself, with a progressive approach of the simulator in several steps distributed on several days, including the familiarization with observers whilst working on simulator.

For the reactor pilots, the main point concerns the means available in terms of documents: procedures must be reviewed and ergonomic design must be obtained for the disturbed situation training.

For both professions, trainees must be able to perceive their knowledge and skills sufficient for the task in the perspective of increasing self-confidence: this implies to create or manage differently the previous steps of their training.

4. Conclusions

Demonstration is made for i) an effective 3-level qualitative scale able to rate stress conditions with regards of qualitative variables, ii) a simple protocol and device able to evaluate short term occupational stress. Tests are successful and suggest a reduced stress coefficient K_{sr} as a relevant and accurate parameter for this kind of stress rating. The Yerkes and Dodson theory (1908) is matched. Application is done successfully with anesthetists' trainees and comparison with reactor pilots' training is done. For both professions, suggestions are made concerning the training improvement. Further applications are planned for both professions in the coming years.

Symbols & Units

Symbol	*Quantity*	*Units (SI)*
HR_{mean}	Mean heart rate	bpm
HR_{max}	Maximum heart rate	bpm
K_p	Performance coefficient	none
K_{sr}	Reduced stress coefficient	none
p	Probability	none
r	Correlation coefficient	none
R^2	Determination coefficient	none

Appendix

The PDI questionnaire in its French version used immediately after taking the test. The 5 levels Likert type scale are used: *pas du tout, un peu vrai, plutôt vrai, très vrai, extrêmement vrai.*

01- Je me sentais totalement incapable de faire quoi que ce soit
02- Je ressentais de la tristesse et du chagrin
03- Je me sentais frustré(e) et en colère car je ne pouvais rien faire de plus
04- J'avais peur pour ma propre sécurité
05- Je me sentais coupable
06- J'avais honte de mes réactions émotionnelles
07- J'étais inquiet pour la sécurité des autres
08- J'avais l'impression que j'allais perdre le contrôle de mes émotions
09- J'avais envie d'uriner et d'aller à la selle
10- J'étais horrifié(e) par ce que j'avais vu
11- J'avais des réactions physiques comme des sueurs, des tremblements et des palpitations
12- J'étais sur le point de m'évanouir
13- Je pensais que j'allais mourir

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