Causes and consequences: two dimensional spaces to fully describe short term occupational stress

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Abstract

The stress which we are interested in this study is a short term occupational stress, while people at work are asked to perform a task bounded in a short time interval (about several seconds to several hours). To characterize the stress, (macro)variables can be distributed among three to six dimensions (McLean, 1974; Palmer et al., 2003). Consequences due to stress are absent of the models. Our work aims to make the demonstration that the consequences (among which behavior) induced by the short term occupational stress are important to fully describe stress. – METHODS: In order to show the importance of behavior to characterize short term occupational stress, we have proceeded in two steps: the first one investigated whether stressful (resp. stressless) conditions gave mainly stressed (resp. non stressed) behavior analyzing performance versus stress, and the second one analyzed how apparent similar stressed subjects might give different consequences in terms of behavior. – RESULTS AND DISCUSSION: Stress in test conditions: Resulting data fulfill the theoretical proposal of Yerkes and Dodson (1908), divided into three main parts: i) the central part reflects the transient state for the subject in terms of stress effects, ii) the left part is linked to the positive state of stress or stable cognitive state, and iii) the right part concerns the negative state of stress or the potential cognitive disorder state. They remind the concept of Human Functional States (HFS) defined by Leonova (2009). The results illustrate the impact on the subject's behavior. Stress in working situations: Observations and interviews with trainers and trainees trained on full scale simulators for risky professions have been done, highlighting how apparent similar state of stresss can lead to different behaviors. It shows that both the source factors of stress and consequences induced by the situation of stress can be useful for its characterization. The two 3-D space model of stress: The conclusion is that stress is fully defined by a two 3-D space concerning source and consequences. The source 3-D is: i) the context dimension, ii) the request or job demand dimension (excluding the context), iii) the subject's characteristics. The consequences 3-D is: i) the psychological symptoms, ii) the physiological symptoms, iii) the behavioral symptoms, or resulting actions. In each 3-D space, the stress is defined by variables on each axis which determines a volume of stress. The first volume finds its consistency through the dimensions interactions and produces the consistency of the consequences volume in which dimensions interact together as psychological symptoms usually produce physiological responses, both making possible or not behaviors. The two spaces interact together, as symptoms produce a feedback on the source.

1. Introduction

This study deals with mental stress. For this reason, tests have been done without any physical effort (subjects are sat), and for application of the developed method, all cases involving strong physical efforts are taken out of the experimental data.

The stress which we are interested in is a short term stress, compared to long term stress linked with chronic stress exposure (refer for example to the studies of Schubert *et al.* (2009) who compare both kind of stress).

In general, stress occurs depending on endo- and exo-parameters for one subject. Endo-parameters can be the physical and psychological state of the subject, and exo-parameters can be the context. The stress will take different forms according to the parameters which will be of significant influence. We can suggest a list of short and long term kinds of stress:

- Stress due to physical demand: intensive short or long term stress mainly due to physiological response of the body (sports, hung up by the feet during yoga).
- Stress due to physical attack: both intensive short and long term stress (war battle field, street aggression).
- Stress due to physical contact with subject's agreement: intensive short term stress (patient in surgical intervention).
- Stress due to psychological exposure, short and sharp: mental intensive short term stress (verbal aggression).
- Stress due to psychological exposure, short and without violence: mental short term stress (taking

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an exam, dealing with a difficult task, physician during surgical interventions).
- Stress due to psychological exposure, long and without violence: mental long term stress (dealing with a difficult task at work for several days, physician during long surgical interventions, chronicle exposure to organizational stress at work).

In this study, we are concerned by mental short term occupational stress, and by its relationship to performance. The precision "short term" is important for the reasons briefly exposed above. In case of long term occupational stress, physiological parameters vary differently. Details are given below.

Different kinds of parameters exist that can contribute to occupational stress. But it would be a mistake to focus just on parameters generating stress for at least two reasons: the first one is that a subject's state of stress is usually induced by a combination of stressful and stressless parameters, and the second state is the fact that one parameter as the noise for example can be stressless (relaxing music) but can become stressful (industrial environment with noisy engines). Furthermore, their combined effects can be different than their individual effects (Liebl et al., 2012). Besides, parameters may depend on the subject or not. We may consider the parameters related to the subject themself which we shall call the endogenous parameters, and the one from outside, the exogenous parameters. The endogenous parameters concern the subject's psychology and physiology, while the exogenous parameters concern all those from the physical and psychological environment: temperature, surrounding noise, interaction with colleagues, time pressure, work load, decision latitude… All these parameters can be more or less stressful depending on their intensity. Some of them can even be stressless as illustrated above with the case of noise, which means that one parameter can evolve on a "one dimensional axis" with positive and negative values of stress. For this reason, instead of speaking of "parameter of stress", we shall prefer to say "variable of stress", according to the following considerations.

Considering the occupational stress, a lot of studies may allow us to build a list of all the variables involved in the rise or decrease of stress. Yet, such an exhaustive list would be a fastidious work with a fuzzy gain: a given work situation is not necessarily concerned by all the variables that could be listed. Some studies have determined specific stress factors for given professions (for surgeons: Arora et al., 2010; for anesthetists: Yee et al., 2005). We thus would conclude that for a given situation, a lot of them are not significant while others are relevant.
We can argue by few examples how a variable can be relevant in a context and not significant in another. For instance: Lazarus (1985) used the Hassles factors and Hopkins symptom checklist among which is "financial responsibility" and "future security". These two variables are macrolabelled and we should rather designate them as "macro-variables": the financial responsibility can be declined, for example, depending on the work activity and on the company where the subject works, as "the responsibility concerning the loss of money for the company due to the accidental destruction of materials", or "the stable financial balance of the team due to a safe management"; and future security may concerns "the stability of the subject's employment" or "the short term security of people at work due to a technical problem". These two macro-variables are giving here four variables. The difference between macro-variable and variable is the refined level of the description of the parameter. These (macro)variables can be concerned related to one or several dimensions of stress.

Many analysis have been done and several models exist to describe stress, performance, and their relationship. Among them for example, Karasek and his team (Schwartz, Pieper, & Karasek 1988) found the between-occupation variance was:
- 4.2 % for psychological demand
- 25.9 % for physical demands
- 34.7 % for control

and so suggested an interesting concept for stress at work (Karasek *et al.*, 1990 & 1998).
An interesting review has also been suggested by Staal (2004).

According to the second theory proposed by Karasek & Theorell (1990), these (macro)variables can be distributed among three dimensions describing the stress: the request or job demand dimension including the context, the subject's autonomy or decision control, and subject's social support perception.
Other models distribute these variables among three different dimensions: the subject's vulnerability, the context, and the stress factors (see Mclean, 1976), or over six dimensions: demand, control, support, relationship, role, change (see Palmer, Cooper & Thomas, 2003). As we shall consider stress at work, the stress is of occupational kind. We shall thus study short term occupational stress, at which people at work are submitted when they are asked to perform a task bounded in a short time interval (about several seconds to several hours). We shall study the relationship between performance and stress, and mainly the influence of the conditions of stress on the performance. Yerkes & Dodson (1908) gave a theoretical description of this relationship, assuming that performance rises with the stress level until a given threshold beyond which stress puts the subject in a cognitive disorder zone making to performance decreasing (Fig. 1).
Yet, in mathematics, the dimension of a space or object is informally defined as the minimum number of coordinates needed to specify each point within it. In a 3-D space, a point is fully defined by a set of 3 coordinates, and every objet is fully defined by a set of coordinates or a set of equations referring to the 3 dimensions. This is possible only if the dimensions are independent from one to another.

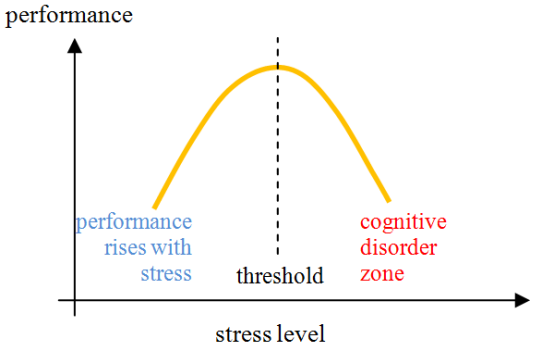

Fig. 1. The Yerkes & Dodson (1908) theoretical description of this relationship performance vs stress: performance rises with the stress level until a given threshold (extreme of the inverted U curve) beyond which stress puts the subject in a cognitive disorder zone making performance decreasing.

The following analysis will show that the quoted models do not match these characteristics ,and that for the considered kind of stress, some dimensions are missing. Specifically, we aim to make the demonstration that the consequences induced by the short term occupational stress are important to fully describe stress. Among them, the behavior as a resulting action is an important variable to be taken into account.

2. Methods

In order to show the importance of behavior to characterize short term occupational stress, we have proceeded in two steps: the first one investigated whether stressful (resp. stressless) conditions gave mainly stressed (resp. non stressed) behavior analyzing performance versus stress, and the second step analyzed how apparent similar stressed subjects might give different consequences in terms of behavior.

2.1 Method - step 1: performance versus stress

According to the knowledge of stressing parameters at work, we built a test (thereafter named "Stress-test") and its context (Stress and No Stress conditions).

The test was made up of 12 questions. A performance coefficient K_p, based on the right answers given by the subject, has been calculated for each subject. The whole test protocol was the same for both Stress and No Stress Conditions. The difference came at the time of taking the test.

Our subjects (N=18; 50% male) were healthy, middle aged (25-35 yo), charter engineers or physicists, French, living in France. Choosing people with the same academic background and the same kind of job is very important, because they are all able to understand and deal with the questions of the test by the same way. It means that the academic background, the professional job, and the social level, are fixed parameters. Heart rate has been measured using a Polar FS2c for physiological measurement of stress.

The whole test protocol was the same for both Stress and No Stress Conditions. The difference came at the time of taking the test.

The subjects were met in their job office. The appointment was always planed between 9:00am and 12:00am in order to avoid post-prandial effect due to breakfast or lunch. They were asked not to smoke or drink any exciting beverage (coffee, tea, cola…) at least one hour before taking the test. Every time, the door was closed and the researcher was alone with the subject, not disturbed. The phone did not ring.

The protocol of the test was as following.
As an introduction, the researcher reminds the subject of the aim of the meeting, and asks him/her to pick a paper randomly among several. This is done so that the researcher does not choose the case which will be studied: the drawing decides whether the subject will work in stress conditions or not. To maintain the balance, the drawing is done every two tests: after one case, the opposite case is always studied.

Then, the researcher explains the need for measurements of the heart rate using a Polar heart rate monitor and the metrology is then applied to the subject. The researcher explains the way it would go on: taking the test, checking together the results, and then the researcher explains why the test is done as it is.

The protocol to obtain the two conditions for taking the test is fully described elsewhere (Fauquet-Alekhine et al., 2012). They are elaborated according to a work analysis of the test conditions done a priori and using the 3-level qualitative scale (see Fauquet-Alekhine et al., 2011 and 2012): i) the Stress Condition has been built to be stressful for the subject, and ii) the stress factors of the so called No Stress Condition has been suppressed or lessened. We called it "No Stress" to simplify writing but in fact, stress does exist during this test as every job demand creates a stress at a more or less important level.

As we can see, for the Stress Condition test compared to the No Stress Condition test, the work context is elaborated for the subject to perceive as many factors as possible as a constrain.
The data obtained have led to match a Yerkes & Dodson curve type.

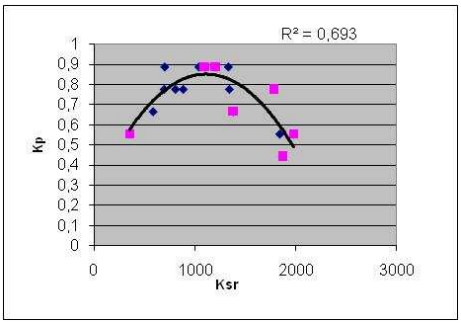

Fig. 2. Experimental data obtained during the Stress-test, plotted with performance coefficient K_p vs reduced stress coefficient K_{sr} and fitting a Yerkes & Dodson (1908) curves for a short mental occupational stress (Fauquet-Alekhine et al., 2011). The determination coefficient of polynomial fitted curve is $R^2 = 0.69$.

The study is based on a previous work (Fauquet-Alekhine et al., 2011 and 2012) in which it was demonstrated that a Yerkes & Dodson curves could be fitted for a short mental occupational stress (Fig. 2): plotting the subjects' performance measured through the performance coefficient K_p vs the state of stress rated by the reduced stress coefficient K_{sr} gives a bell curve where subjects working in stressful conditions are well discriminated on the right side of the graph (clear squares) from other subjects.

These results are now used to conceptualize what have been named above abusively No Stress and State of stresss according to the theoretical suggestion of Yerkes & Dodson confirmed by our finding.

2.2. Method - step 2: apparent similar stress for different type of stress.

The second step has been induced by a basic remark shared by several trainers working on full scale simulators, saying that trainees were trained to deal with stress as they were stressed during simulation training sessions. The question then was to know whether the stress induced on simulator was the same than during work in non-simulated situations.

This has led us to perform observations and interviews with trainers and trainees trained on full scale simulators for risky professions. Observations have been done both in simulated and non-simulated situations. The professions concerned by observations and interviews were aircraft pilots, harbor pilots, and nuclear reactor pilots, all working in French companies.

3. Results & Discussions

3.1. Stress in test conditions

Resulting data obtained with the Stress-test fulfill the theoretical proposal of Yerkes and Dodson (1908), suggesting that a stressed subject will have a better performance than if not stressed until a given threshold. Measurements have been conducted in a context of training on simulator, and results have shown the same differentiation: a stress threshold separating non stressed subjects from others. Application of these conclusions has been done for event analysis in industry to illustrate how the potential cognitive disorder state induced by stress could produce an inadequate behavior (Fauquet-Alekhine *et al*., 2011).

Thus, in case of mental short term occupational stress, the stress has a positive effect on the performance until this threshold, and beyond it, subjects are less performing because the effect of stress becomes negative: subjects may be concerned by cognitive disorder that makes them unable to perform correctly the task.

Our findings thus suggest that the Yerkes and Dodson curve can be divided into three main parts:

- the central part reflects the transient state for the subject in terms of stress effects,
- the left part is linked to the positive state of stress or stable cognitive state,
- the right part concerns the negative state of stress or the potential cognitive disorder state.

These different states remind the concept of Human Functional States (HFS) defined by Leonova (2009). They are drawn on the graph presented in Fig. 3.

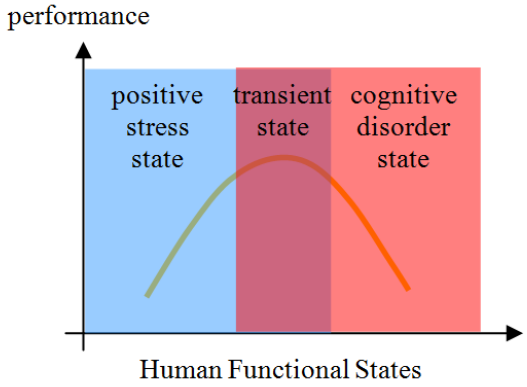

Fig. 3. Human Functional States (HFS) divided into three main parts: i) central part: transient state for the subject in terms of stress effects, ii) left part: positive state of stress, iii) right part: potential cognitive disorder state.

With regards to these proposals, what have been named abusively in previous sections No Stress and State of stresss can be now refined as three main levels of HFS defined as follows:

- Low potential of stress (LPS)
- Efficient potential of stress (EPS)
- High potential of stress (HPS)

Application of these results has been done for event analysis in industry as follows. On an industrial plant (more than 1000 employees), the work analyst has been called upon in order to find the causes of the action of a field worker who had opened a valve while it was forbidden and had provoked an important loss of production with potential safety consequences. It happened in 2009, while the company had made great efforts during the past years to make the interventions more reliable, and the management did not understand how such an act could have happened. When the work analyst has met the field worker, he has asked him to explain the whole story in details. The work analyst was astonished by one detail: during the first half part of the story, the field worker appeared to work as a good professional, but during the second part, he appeared to work as a man who did not know the job at all. During the interview, the analyst has noticed several details which showed that in work situation during the second part of the story, the field worker was frightened. Step by step, the analyst has put into light that the worker was able to work as a good professional until the time he had entered a room containing valves and ducts with high vapor pressure. Then he discovered that the worker had known, several years ago, some colleagues being injured by vapor loss in such a room, and that entering the high vapor pressure room was frightening him. Scared by the place probably induced by the remembrance of the colleagues' accident, the field worker could not work anymore correctly. The frame of this event matches HFS defined above as the potential cognitive disorder state.
Furthermore, this example illustrates how the potential cognitive disorder state induced by stress can produce a inadequate behavior.

These results illustrate that the way the subject is able to perform the task using know-how and skills depends on the HFS, and the HFS may determine the subject's behavior.

3.2. Stress in working situations

The previous results show that the behavior can appear as a consequence or a result of the stressed state of the subject. The following intends to demonstrate that similar apparent stressed states can yet be related to different behaviors. For this aim, observations and interviews with trainers and trainees trained on full scale simulators and on non simulated situations for risky professions have been done. Stressful situations have been observed and put into discussion during the interviews.

An aircraft instructor explained having lived a very specific situation, just once in his life. He was training a team for aircraft piloting on full scale simulator. This simulator was equipped of screens in place of the windows to reproduce the outside of the cockpit, and installed on hydraulic motion in order to reproduce the movement and vibrations of the plane during the flight. While the team had some difficulties to perform the task, the simulated flight derived to a simulated dramatic situation the end of which would be the crash. According to pedagogical goals, the instructor let the team try to deal with the problem, unfortunately without any success and the plane was falling down at high speed. On the screen, the ground was approaching more and more. In the cockpit, vibrations were increasing. The 2-pilot team was doing its best in vain and when the screens showed the ground up to the plane, the pilots put their arms on their face to protect themselves from the impact. But they were on simulator! The instructor was very surprised of such a behavior. According to him, in this specific case, the trainees had felt a stress similar to what could be felt in a non-simulated situation, and the pilots had acted exactly as if everything was a real potential crash and finally, with their arms on the face, as a real crash.

In this case, it is difficult to claim whether pilots' stressed states are similar or not between simulated and non-simulated situations. Anyway, they are rare. The following examples are more common.

Interviews with a Merchant Navy trainer pointed out that the observed stress could seem to be the same in non-simulated and simulated situations (Fauquet-Alekhine, 2011), but in fact not. This similarity only concerned the symptoms. When the resulting action was considered, what was done by the stressed trainee on simulator was not the same than what was done by the same stressed person in non-simulated situation. It depended on the source of stress: on simulator, the trainee was stressed because of the evaluation (source), and he was leading the ship close to the edge very slowly (consequences), while in the real harbor, the subject was stressed because of the workload and the number of vessels waiting to enter the harbor (source). He then led the ship close to the edge much faster (consequences). In this case, the state of stress seemed to be the same in simulated and non-simulated situations through the symptoms, but differed through the induced behavior.

Interviews with a safety expert working on a nuclear power plant and trained to pilot nuclear reactor in accidental situations gave the same result. The trainee explained that he had co-piloted a reactor in accidental situation twice during his career (4 years). He said that in these situations, he felt a stress and his main concern was the safety of the industrial plant and its environment (source). Everything he did in these working situations

was induced by this concern: act fast and efficiently (consequences). But on the simulator, it was quite different: dealing with the reactor piloting in case of accidental situations, his main concern was to prepare the following debriefing with the trainers (source), during which he would have to show his good understanding of the situation. For this aim, the way he took more time to read the procedure, and the kind of information he had gathered (consequences) were quite different and more numerous than during a non-simulated situation. Nevertheless, during both situations, he felt the same state of stress. In this case, the state of stress felt by the subject seemed to be the same in simulated and non-simulated situations through the symptoms, but differed through the induced behavior.

This has highlighted how apparent similar HFS of stress can lead to different behaviors. As we have seen, the difference is due to the stress source. Thus, the source factors of stress are important to characterize the stress. But these examples also show that consequences induced by the situation of stress can be useful for this characterization. If we think to the graph shown on Fig. 3, each HFS can be related at least to two different subject's behaviors, linked both with the source and the aimed action envisaged by the subject.

We have obtained similar observations for aircraft pilots, nuclear pilots, and anesthetists. Here, we can suggest that the behavioral symptoms must be taken into account to define the stress. These findings lead us to suggest the Stress model presented in the next section.

3.3. The two 3-D space model of stress

According to us, an adequate model of the stress phenomenon must be based on independent dimensions as said above. When we check all our studied cases, we find some relationship between factors.

Our own observations show that:

- If context does not include all stress factors, many Stress factors are part of the context. Thus stress factors and context cannot be thought as two different dimensions since not independent.
- Effective subject's autonomy depends on the organizational context, which let us suggest that the appropriate dimension is context rather than autonomy.
- Subject's perception depends on subject's state, i.e. subject's characteristics. They are also called sometimes subject's vulnerability (Polevaya et al., 2010), but it is an inappropriate noun as it must be also considered the subject's strength.
- Social support and relationship are not independent.

The conclusion is that the appropriate dimensions are:

- the context dimension (social, organizational, environmental),
- the request or job demand dimension (excluding the context),
- the subject's characteristics.

Subject's characteristics refer to the psychological abilities of the subjects to be sensitive or not to stressful conditions (for exemple: Zvolensky et al., 2005), and these refer themselves to physiological characteristics as demonstrated by many researches. For example, Albert, Shchepina et al. (2008) showed that rats could be more or less tame according to adrenal glands size, levels of serum corticosterone, blood glucose levels, concentrations of amino acids, serotonin and taurine levels.

But our aforementioned observations show that these three dimensions are not sufficient to fully describe the stress phenomenon; as a matter of fact, we must admit that this 3-D model only describes the source of stress. In the interactional approach, the stress is a result of the interaction of the three dimensions which produce consequences that themselves describe the stress by what we call "symptoms" (Fauquet-Alekhine et al., 2011). Symptoms are consequences of specific stimuli; they are responses of the subject to these stimuli. We shall gather here subjective and physiological consequences as "symptoms" (including "signs", while the strict meaning of "symptom" would only concern the subjective consequences, the objective ones being designated by "signs"). Symptoms may be physiological, psychological. As an extension, we can also speak of behavioral symptoms.

Physiological symptoms can be measured as heart rate for example, and psychological symptoms can be observed through physiological symptoms or known through questionnaires of perception. According to these symptoms (Fauquet-Alekhine et al., 2012), one can define the type of stress and its intensity. Here, we can see that the symptoms must be taken into account to define the stress.

The conclusion is that stress is fully defined by two sets of dimensions concerning on one hand the sources and, on the other hand, the consequences.

As described above, the appropriate set of dimensions describing the sources is 3-D:

- the context dimension,
- the request or job demand dimension (excluding the context),
- the subject's characteristics.

And the appropriate set of dimensions describing the consequences is also 3-D:

- the psychological symptoms,
- the physiological symptoms,
- the behavioral symptoms, or resulting actions.

In each 3-D space (Fig. 4), the stress is defined by variables on each axis which determines a volume of stress. The first volume finds its consistency through the interactions between the three dimensions (context – demand – subject's characteristics), and produces the consistency of the symptoms volume in the second 3-D space (psychological – physiological – behavioral). These three dimensions interact together as psychological symptoms usually produce physiological responses, both making possible or not such behaviors. And the two spaces interact together, as symptoms produce a feedback on the source.

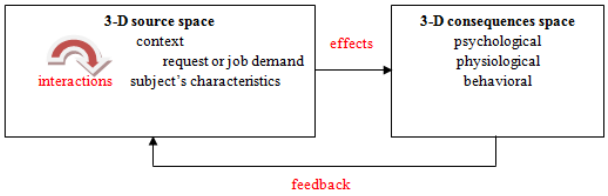

Fig. 4. The two 3-D spaces model for short term occupational stress

Unfortunately, this full description of stressed HFS, if can serve the characterization, may not always serve the predictive extrapolation: as stressed HFS is contextual, a given subject in a given stressful context α related to a HFS described by variables in the two 3D-spaces will not necessarily be the same in another given stressful context β. Similarly, if context α is more stressful than context β, the subject will not necessarily be more stressed in context α than β.

Proof is the following results which reinforce the suggestion that consequences are of great importance to fully describe the HFS as consequences vary from one subject to another in a given context.

Among the subjects participating at the Stress-test experiments described in sections 2.1 and 3.1, three of them were involved in a training program for having a new job in the same company. For this aim, they had to take exams both on simulators and in front of an examinatory board. We have compared the results obtained at the Stress-test and the results in front of the examination board, for each subject, named A, B and C. This has been done to evaluate the influence of the contextual effect on the stressed subject's behavior, and to weigh up the importance of the subject's behavior to characterize the HFS. Evaluation of the perceived stress has been done using the PDI questionnaire according to our previous work (Fauquet-Alekhine et al., 2011 and 2012). Results are shown on Fig. 5, for both contexts: Stress-test and examinatory board.

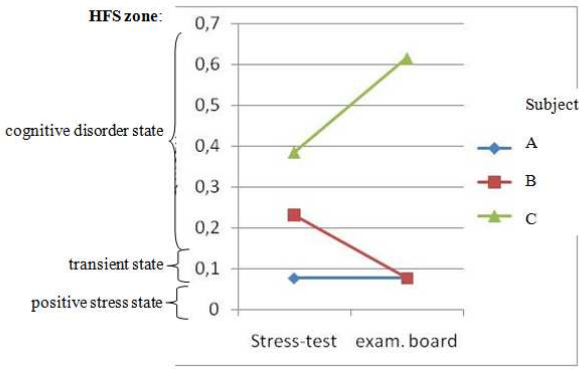

Fig. 5. Comparison of HFS for subjects A, B and C for two different contexts: taking the Stress-test and in front of the examinatory board. Evaluation of the perceived stress has been done using the PDI questionnaire according to Fauquet-Alekhine et al. (2011).

The results show three different cases for each subject:

- subject A remains in transient HFS for both contexts: Efficient potential of stress (EPS),
- subject B varies HFS from potential cognitive disorder HFS (HPS) to transient HFS (EPS) corresponding to the threshold zone defined by Yerkes and Dodson,
- C increases the level within the potential cognitive disorder HFS (HPS).

It appears here clearly:

- the contextual character of stressed HFS and the great influence of the variables linked with the subjects' characteristics identified inside the 3-D source space of the model proposed in section 3.3,
- the behavioral variation from one subject to another showing that consequences are important to the description of HFS.

4.Conclusion

On the basis of the study of performance vs stress, we have shown how the mental short term occupational stress had to be fully described in a two 3-D spaces model. We have questioned the apparent limits of this model in terms of predictive extrapolation from one known situation (including the subject) to another. Further investigations will be conducted to analyze the performance level vs stress related to the context and also to analyze whether the subjects' characteristics identified within the 3-D source space of the model may be characterized in order to refine the predictive nature of the model.

According to the results that we shall then obtain, the stress management will be think in term of dealing with

the context variable (changing the context influence; see Fauquet-Alekhine et al., 2011) or dealing with the subject's characteristic within the context through self-regulation (Kuznetsova et al., 2005; Leonova et al. 2009 & 2010).

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